SIMULATION ANALYSIS OF AN OUTPATIENT CLINIC

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This work is affectionately dedicated to the author's wife Cam whose love and patient understanding made this effort possible and to his parents who have been a constant source of guidance and encouragement throughout his life.

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SUMMARY

The purpose of this study was to investigate the relationships between the time spent by patients in obtaining medical services and the alternative staffing levels, policies, and projected operating conditions in a large outpatient clinic which dealt primarily with walk-in patients. The intent of the investigation was to provide an analysis which would assist hospital management officials in making decisions in an attempt to improve the service characteristics of the system.

Data were collected in the existing system, and a simulation model was developed. An experiment was designed to permit the prediction of the probable performance of the system under the operating conditions of interest, to allow an assessment of the changes that occur in the time spent by patients in obtaining medical services as one or more of several factors are varied, and to permit a statistical evaluation of a proposed change in operating policies. Estimates of the measures of system effectiveness were obtained from the data generated by the model. The analysis of results indicated that the number of physicians available for duty in the clinic, the level of patient input, and the interaction between these variables have a significant effect upon the mean time spent in obtaining medical services. The analysis also indicated that a significant reduction in the mean time spent in obtaining medical services could be achieved by adopting the modifications to existing patient scheduling policies which were proposed in the study.

Since this investigation was concerned with analyzing the patient flow in a specific outpatient system, the results and conclusions which were obtained are applicable only to that system. However, since many outpatient clinics operate in a similar manner, the method of attack and techniques of data collection and model building presented herein should be applicable to the analysis of many outpatient operations.

CHAPTER I

INTRODUCTION

Objectives

The purpose of this research was to investigate the relationships between the time spent by patients in obtaining medical services and the alternative staffing levels, policies, and projected operating conditions in a large outpatient clinic. The intent of this investigation was to provide an analysis which would assist hospital management officials in making decisions in an attempt to improve the service characteristics of the system. The specific objectives of the study were:

1. To develop a simulation model which could be used to analyze the probable results of proposed management policies or anticipated changes in operating conditions in the clinic and certain adjunct facilities.

2. To collect real data within the existing system for use in model building and analysis.

3. To determine probable patient waiting times for different levels of staffing over the range of current and projected patient input levels.

4. To examine alternatives for improving the service characteristics of the system.

Background

For 196 years the United States Army Medical Department has provided medical support for the Army. During this period great advances have been made in the prevention and treatment of disease and injury. Perhaps at no time during these years has the motivation for continuing improvement in the management and control of medical service been so apparent. This pressure for the betterment of health services is the result of many factors in our society, both within and outside the military community. The national shortage in the supply of physicians has been widely publicized as one of the primary causes of the long waiting lines and high cost of medical care which is prevalent in our society today. Steps are being taken on a national level to relieve that shortage; however, relief as a result of these measures will likely be years in materializing [1, p. 1484]. In the meantime other methods must be explored to improve the situation.

Within the military community the pressure for change is particularly strong. As the nation proceeds on its announced course toward the development of an all volunteer armed force, the importance of high quality, efficiently administered medical care as an inducement to attract and retain military personnel is felt to be significant. Recognition of this fact is widespread within the armed services. It is apparent in a recent article by Brigadier General Manley G. Morrison, Chief, Army Medical Service Corps.

> A Volunteer Army--smaller, more highly paid--will be expected to operate more effectively. Wasting scarce manpower in long waiting lines for processing and for receipt of services will have to be absolutely minimized, not only to conserve manpower, but also

> to eliminate the legitimate irritation that such lines create .... If we are going to rationally organize and administer a health care system that will attract and retain, instead of repel, young Americans, it must be a system designed not for our own convenience, but rather for the convenience of the persons it is designed to serve. [2, p. 27]

In pursuing these goals, the Army Medical Service has expressed a desire to explore the use of recent advances in operations research and management science techniques. This study represents an attempt to use one such technique in attacking the problem.

The setting for the study was the United States Army Hospital (U.S.A.H.), Fort McPherson, Georgia, a 90-bed medical treatment facility which provides many varied services to the thousands of active and retired military personnel and their dependents at Fort McPherson and in 43 counties in Georgia, five counties in North Carolina, and 32 counties in Tennessee. The inpatient capacity of the hospital is not indicative of the volume of medical care which is administered within the facility. Approximately 14,000 persons are treated each month in the outpatient clinics of the hospital. This results in over 39,000 medically related treatments per month.

Though the Army is undergoing a general reduction in personnel, no decrease in the patient load is anticipated at the Fort McPherson Hospital. This is due to the fact that the post houses a major headquarters element (Headquarters, Third United States Army) and serves a large number of non-active duty personnel over a wide geographical area.

This study was motivated by an interest on the part of hospital officials in investigating the service characteristics of one of the outpatient clinics. In particular, hospital officials were interested in determining what effect different levels of staffing would have upon the time spent in obtaining medical services in the pediatric clinic and whether certain changes in operating policies might increase the efficiency and effectiveness with which medical services were delivered.

The pediatric clinic is an outpatient facility which provides medical services to patients 14 years of age and under. Approximately 1600 patients per month are examined in the clinic. It is primarily a "walk-in" clinic, e.g. the majority of patients arrive without an appointment.

Two categories of patients are subject to scheduling. These are designated "well-baby" and "physical examination" patients by the clinic. Patients in the well-baby classification are children one year of age and under who are scheduled for examinations at regular intervals. Each child in this category is given an appointment for a routine examination at ages six weeks, three months, six months, and 12 months. It is desirable to separate these children from sick children. Physical examination patients are children over one year of age who are scheduled for routine examinations. These include pre-school and pre-camp physicals, and consequently, are concentrated in the summer months.

The pediatric clinic is authorized four pediatricians, one nurse's assistant, and one medical specialist by Table of Distribution and Allowances (TDA) number 3AWZMNAA04, Department of the Army, dated July 15, 1970. The clinic currently operates with three assigned pediatricians and its remaining authorized staff, plus the assistance of Red Cross volunteer workers.

The clinic operates Monday through Friday from 8:00 a.m. until 4:00 p.m. Wednesday mornings are set aside exclusively for well-baby patients in an effort to isolate these infants from sick children.

Method of Attack

To accomplish the objectives cited above, a method of attack was needed which would permit the prediction of the service characteristics of the hospital under a set of assumed conditions. Simulation is the process of producing models and model state histories with the objective of predicting or studying system behavior. It is a technique by which the researcher can incorporate the essential characteristics of the physical system which is to be studied into a mathematical model.

Complex systems whose size and complexity defy an analytical solution are particularly amenable to simulation. In building a simulation model, the researcher need not attempt to describe directly the overall system behavior. Instead, an attempt is made to characterize individual events which take place in components or subsystems. Finally, the interrelationships of the events and components within the system are characterized. The result is a model which effectively portrays those aspects of system behavior which the researcher considers important. This model can then be used to analyze the probable behavior of the actual system under conditions which would be extremely difficult or too costly to study by manipulating the real system.

The clinic can be viewed as a large scale queuing system. Patients are the individual elements which flow through the system and compete for service at various stages in the flow. When the rate of demand for service exceeds the capacity of an individual element or subsystem to provide service, waiting lines or queues are generated.

The first step in the conduct of this study was the development of the simulation model. To accomplish this, interviews were conducted with individuals who had a close working knowledge of the system, and the day-to-day operation of each component of the system was observed over a period of several days.

Having thus gained a thorough familiarity with the system and its operation, the author was able to identify measures of effectiveness which would permit a realistic evaluation of the system with regard to the objectives of the study. Two such measures were chosen initially. These were the total amount of time a patient spent in obtaining medical services and the utilization of physicians (percentage of time physicians are engaged in the examination and treatment of patients and in associated activities such as updating patients' medical records).

A model was then constructed which characterized the operation of the elements of the system and the important relationships between the components. Real data were collected within the existing system to permit this characterization, and the operation of the components of the model were validated through the use of these data.

Once the model was completed, an experiment was designed to permit the exploration of the probable performance of the system under the operating conditions of interest and to permit testing the statistical significance of a proposed change in operating procedures. The model was then manipulated using a digital computer. The results of 144 simulated days of clinic operation were analyzed and presented to hospital management officials.

Scope and Limitations

This research was concerned with analyzing the patient flow within a specific outpatient system, the Pediatric Clinic, U.S.A.H., Fort McPherson, Georgia. Hence, the results and conclusions obtained herein are applicable only to that system. They are not in general applicable to other outpatient or pediatric operations. However, since a great number of military outpatient clinics and many civilian outpatient operations as well operate in a manner quite similar to the clinic studied herein, the method of attack should be applicable to the analysis of many outpatient operations in this country. A similar analysis of such an operation could be accomplished with relatively little difficulty by collecting the appropriate data (arrival distributions, service time distributions, routing probabilities, etc.) and adapting the model to accomodate the local operating policies and parameters.

This study focuses on the relationship of the specified measures of effectiveness to the variation of the input variables. It makes no attempt to incorporate other measures relating to the patients perception of the quality of medical care. Though the reduction of patient waiting time is a worthwhile objective, it must be augmented by a high degree of personal interaction between all members of the clinic staff and the patient. The quality of this interaction must go hand-in-hand with such quantitative measures as those emphasized in this study in order to determine the total patient perception of the quality of medical care.

CHAPTER II

LITERATURE

The origins of the hospital are difficult to date. Speculation concerning the genesis of the hospital in the early history of man is primarily a function of how a hospital is defined by a particular author. Smalley and Freeman note the association of religion with the practice of medicine as early as 4000 B.C. They also chronicle the origins of the military hospital.

> The use of superstition and magic as a means of ministering to the sick and injured was an accepted practice of witch doctors in ancient tribal communities, and the assemblage of wounded warriors following tribal combat was the earliest known form of military hospital, dating back to about 2900 B.C. [3, p. 17]

Forerunners of the modern organized hospital have been identified in most of the major cultures which have arisen in history. However, much of the progress in medical care and treatment apparently died with the expiration of the civilization which gave it birth.

The first mention of outpatient service appeared in 1664 in the early journals of an English hospital [4, p. 31]. From shortly thereafter until the present an increasing concern can be found in English literature on the subject of outpatient service. The concept of outpatient care became an integral part of the English system of voluntary hospitals which were established beginning about 1700 [3, p. 21]. The amount of care administered on an outpatient basis grew slowly at first. But in the early

1800's the number of outpatients attending English hospitals began to grow rapidly. Overcrowding was the result. In 1869 the report of an investigation of the outpatient departments in London reveals conditions which many might feel accurately describes some outpatient clinics today. "The investigators reported delay, gross overcrowding, rapid and perfunctory examination and prescribing, and a general lack of privacy and consideration for the comfort and feelings of patients." [4, p. 31] Subsequently, efforts have been made over the years to improve the quality and efficiency of service in outpatient departments.

Since 1905 the role of the outpatient departments in England has been different from that which exists in the United States. Its function as a part of the National Health Service is to provide examination and treatment upon referral of patients from general practitioners. Since the physicians and other clinic personnel are salaried government employees, the efficiency with which service is provided has been a matter of public concern. Hence a great deal of the current research in the area was carried out in England.

Welch and Bailey [5] discussed the importance of an efficient appointment system in attempting to reduce patient waiting times. They noted that one cause of excessive waiting times was an attempt to insure that doctors' time would never be wasted. They constructed mathematical models in an attempt to achieve some balance between physicians' idle time and patients' waiting time by minimizing the sum of the two. They concluded that a reasonable balance could be obtained by giving patients appointments at intervals which corresponded to the average consultation time. This is the first mention of this philosophy which has since been espoused by several contributors to the literature.

The work of Welch and Bailey is indicative of the trend in the English literature on this subject. Because patients attending outpatients clinics are referred by general practitioners, they are, on the whole, subject to scheduling. Thus the solution to the problem becomes a matter of finding the optimum scheduling system. Investigations in this area have been numerous [6,7,8,9].

One aspect of the Nuffield studies [4] was an investigation of outpatient departments of a number of different hospitals in Britain. The different scheduling practices of the outpatient departments of these hospitals provided the investigators with an opportunity to compare the associated waiting times with regard to scheduling procedures. It was concluded that a major cause for delay in the clinics was the scheduling of patients at a rate disproportionately greater than the average service rate. Patients were observed to have spent less time in obtaining medical care in the clinics which attempted to schedule patient arrivals at a rate more nearly equal to the average consulting rate.

More recent studies in both this country and England have increasingly relied upon operations research techniques. Simulation, in particular, has been widely used. One of the first attempts to apply the technique of simulation to a problem of this sort was reported in 1959 by Gabrielson [10]. A manual simulation was used to evaluate a proposed change in the pattern of patient flow in an outpatient clinic under certain assumed conditions of patient input. The results indicated that the proposed system of patient flow would result in a decrease in patient waiting time in the clinic.

Simulation has also been used to aid the facilities planning process in hospitals. Most attempts have concentrated upon forecasting the number of examining or operating rooms which would be required to effectively process a predicted number of patients [11,12,13]. Sumner [14] reported the development of a methodology for long range facilities planning which relied heavily upon simulation.

Several other studies have used simulation to analyze alternative appointment systems and the ramifications of patient scheduling in outpatient clinics. In a study undertaken in 1952 and reported in 1964, Jackson [15] analyzed the operation of a physician in private practice. He modeled the practice as a single server queuing system and tested alternative scheduling schemes by computer simulation. His analysis led to the conclusion that a good balance could be achieved between patient and physician waiting times by scheduling patient arrivals such that "... the ratio between average consulting time and the patient interarrival time is between .85 and .95 ...." [15, p. 222]

Other types of appointment systems have also been advocated in the literature. White and Pike [16] proposed a new type of scheduling procedure in which several patients were scheduled at intervals much smaller than those normally associated with block scheduling procedures.

Another appointment system was proposed by Soriano [17]. In this system two patients were scheduled simultaneously at an interval approximately equal to twice the average service time. This system compared quite favorably with the one-at-a-time scheduling system in Soriano's analysis.

None of the previously mentioned studies grapples with the problem of the walk-in patient. This is certainly understandable in the British outpatient environment because patients are referred to the clinic by general practitioners and, hence, walk-ins are practically non-existent. However, in this country, outpatient clinics must often perform the functions of initial diagnosis and treatment. Hence, the walk-in patient represents a problem which cannot be neglected. Though the literature contains no reference to studies of clinics which are predominantly walk-in, several studies consider the effect of walk-ins upon scheduled clinics.

One attempt to include an analysis of the effect of walk-in patients [18] led to the conclusion that they could be accommodated in the time slots of no-shows.*

This philosophy was refuted by Fetter and Thompson [19]. They argue on the basis of two studies which were undertaken in Air Force hospitals in 1963 that an imbalance often exists between the number of no-shows and the number of walk-ins in a particular clinic. The Fetter and Thompson study also uses simulation to assess the effect of several variables upon patient waiting time and physician idle time in a scheduled outpatient clinic operation which allowed walk-ins. Several notable conclusions were drawn from the analysis of simulation results. Increasing the patient load (percentage of available appointments filled) was found to increase patient waiting time and decrease physician idle time. Both physician and patient unpunctuality were found to have the effect of increasing

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*Patients who arrive without appointments.

patient waiting times. It was also concluded that clinic productivity was lowered with no effect on waiting times when the interval between appointments is greater than the average service time. This study represents an important contribution to the literature. However, the study made no attempt to investigate the service characteristics in a predominantly walk-in, as opposed to scheduled, clinic environment.

Two recent studies [20,21] follow along the same lines as the Fetter and Thompson study. Both papers report attempts to improve the existing clinic operations by altering the operating policies within the system. Since both studies deal exclusively with scheduled clinic operations, neither provides additional insight into the walk-in patient problem.

The results of the literature survey indicate a general lack of information concerning the analysis of outpatient operations which cater primarily to the walk-in patient. Although the problem presented by the walk-in patient has been identified, it has either been disregarded completely in quantitative analysis or treated indirectly as a disrupting phenomenon which complicates the operation of scheduled clinics. The study described herein attempts to investigate the operating characteristics of an outpatient clinic which deals primarily with walk-in patients. In addition to providing information for use by management in the hospital under study, the results should be of general interest because of the lack of published material relating to walk-in clinics.

CHAPTER III

MODEL

Preliminary investigation of the clinic operation led to the conclusion that the facility could best be characterized for the purposes of this study as a large scale service system. This system is composed of elements which have the capability to provide various services upon demand. The units of flow are patients who enter the system to obtain medical services at one or more of the individual service facilities within the system. Because service facilities--doctors, technicians, equipment, etc.--are not available in unlimited quantities, waiting lines or queues are formed as patients compete for these scarce resources. Each patient must pass through several of these service facilities and thus faces the possibility of having to wait for service at each station.

An early step in the analysis was the development of a flow diagram to depict in simplified form the general flow of pediatric patients through the system. Figure 1 illustrates graphically the entry points and paths of flow of the different categories of pediatric patients within the system. Since the system includes facilities which serve all out-patient clinics of the hospital, the pediatric patients must also compete for services at these stations. Hence, it was necessary to incorporate these system characteristics into the model because of their influence upon the time spent by pediatric patients in obtaining medical services. A flow diagram of the system which illustrates this feature is shown in Figure 2.

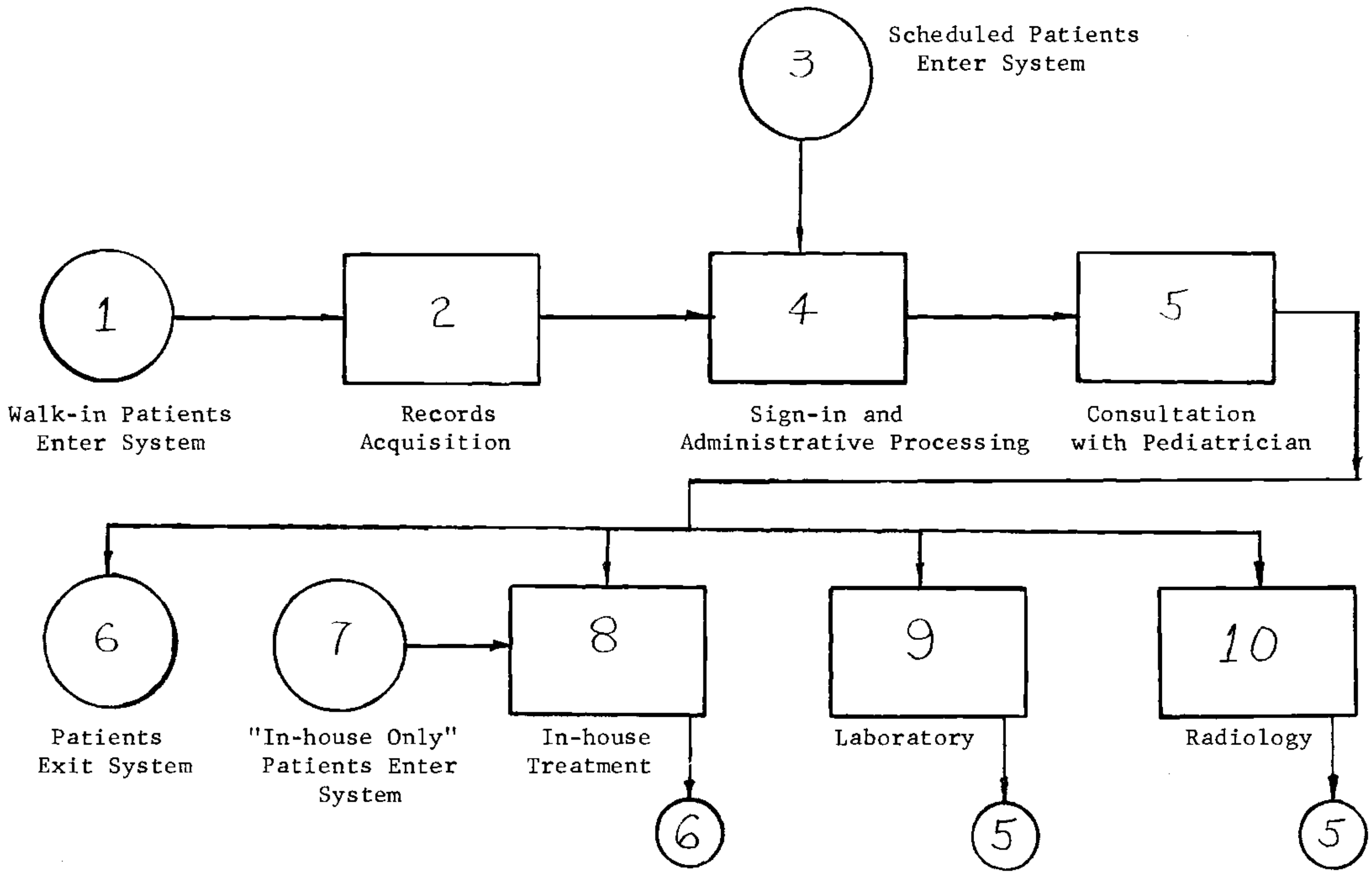

Figure 1. Pediatric Patient Flow

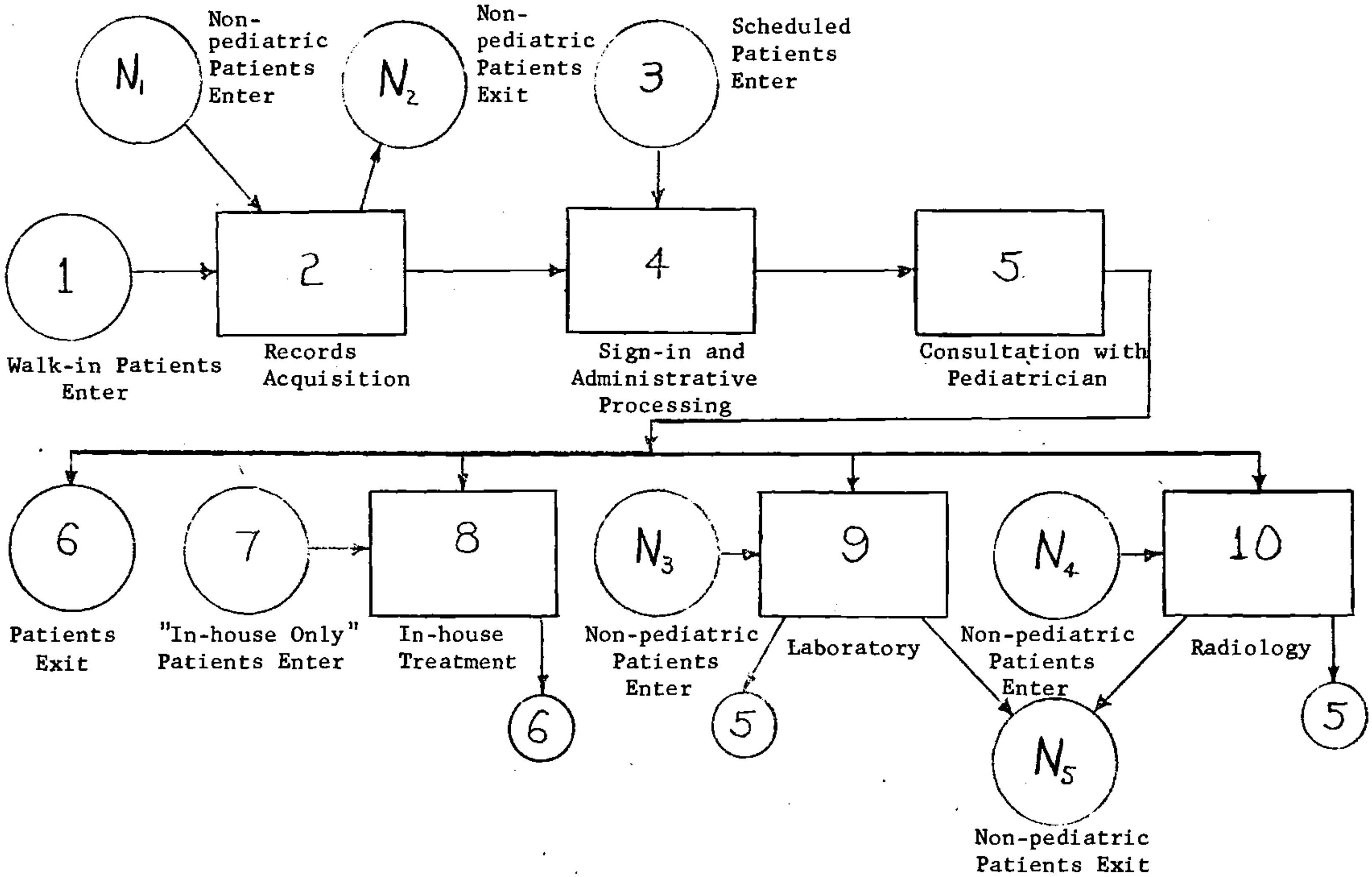

Figure 2. Pediatric and Non-pediatric Patient Flow

General System Description

For the purposes of this study, the "system" is composed of the pediatric clinic and those adjunct facilities within the hospital complex which have an influence upon the time spent by pediatric patients in obtaining medical services. These include the records acquisition facility (records room), the radiology facility, and the medical laboratory.

The pediatric clinic operates Monday through Friday of each week. Under the current operating policies Wednesday mornings are reserved exclusively for well-baby patients. Walk-in patients are permitted entry to the clinic on Monday, Tuesday, Thursday, and Friday between the hours of 7:30 a.m. and 3:30 p.m. and on Wednesday from noon until 3:30 p.m. All administrative and technical personnel who staff the clinic provide services during these hours. Pediatricians who are assigned to the clinic do not become available to provide services until 8:00 a.m. Consultations with patients begin at that time with the exception that one of the assigned pediatricians is required to make a daily visit to the nursery at 8:00 a.m. The services of this physician are not available in the clinic until his return from the performance of this duty. Each pediatrician is authorized a one hour lunch break. In addition, it is accepted practice for each pediatrician to take two coffee breaks daily, one each in the morning and afternoon. Operation of the clinic is terminated daily at 4:00 p.m. or when the last patient has exited the system, whichever is later.

The records room is in operation 24 hours a day. During the hours of pediatric clinic operation two servers are available continuously to obtain the medical history records for walk-in patients. Laboratory service is also provided continuously during the hours of pediatric clinic operation. Radiology service for the categories of patients described in this study begins at 8:00 a.m. and continues throughout the duration of pediatric clinic operation. This facility contains three x-ray rooms which are staffed continuously during this period; however, two of these rooms are reserved for scheduled procedures from 8:00 a.m. until 10:30 a.m. daily.

Two broad categories of patients may enter the system. They are designated pediatric and non-pediatric for the purposes of this presentation. The latter category is composed of patients who make no demand upon the services offered in the pediatric complex, but who may have an effect upon the time spent in the system by the pediatric patients. These patients affect the flow of pediatric patients at three points in the system: the records room, the laboratory, and the radiology department.

There are three types of pediatric patients: walk-in, scheduled, and "in-house only." The latter classification denotes patients who make a demand for service only at the in-house treatment facility. The majority of these patients are individuals who require immunizations or certain pharmaceutical items which are stocked in this facility. These patients enter the system at the in-house treatment facility. They wait for and obtain service therein and then exit the system. Well-baby and physical examination patients constitute the scheduled category. These patients are scheduled by hospital central scheduling for entry into the clinic at a specified time and date. Since records for scheduled patients are distributed to the clinic prior to the designated appointment time, patients in this category proceed directly to the pediatric clinic and enter the system by reporting to the sign-in desk. After providing the necessary information to the Red Cross volunteer worker located there, these patients wait for and obtain the services of a pediatrician. Upon completion of the examination, these patients depart the system.

Walk-in patients constitute the majority of input to the clinic. They are further classified as emergency, recheck, or routine. Patients in the latter two classifications are required to obtain their medical records before proceeding to the pediatric clinic. Upon entering the clinic (Figure 3), the patient must present his records at the sign-in facility A and be processed there. At this station each patient provides a brief statement of the nature of his illness and states his preference for a particular pediatrician if he so desires. He is given a priority based upon his classification and the apparent nature and severity of his illness. Priorities in descending order are as follows:

1. Emergency
2. Return*
3. Appointment
4. Recheck**
5. Routine

When processing has been completed at the sign-in facility, patients

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*Patients who return for reconsultation after having been referred earlier on the same day to the laboratory or x-ray.

**Patients who have been directed by a pediatrician to return to the clinic for a recheck of symptoms noted at an earlier date.

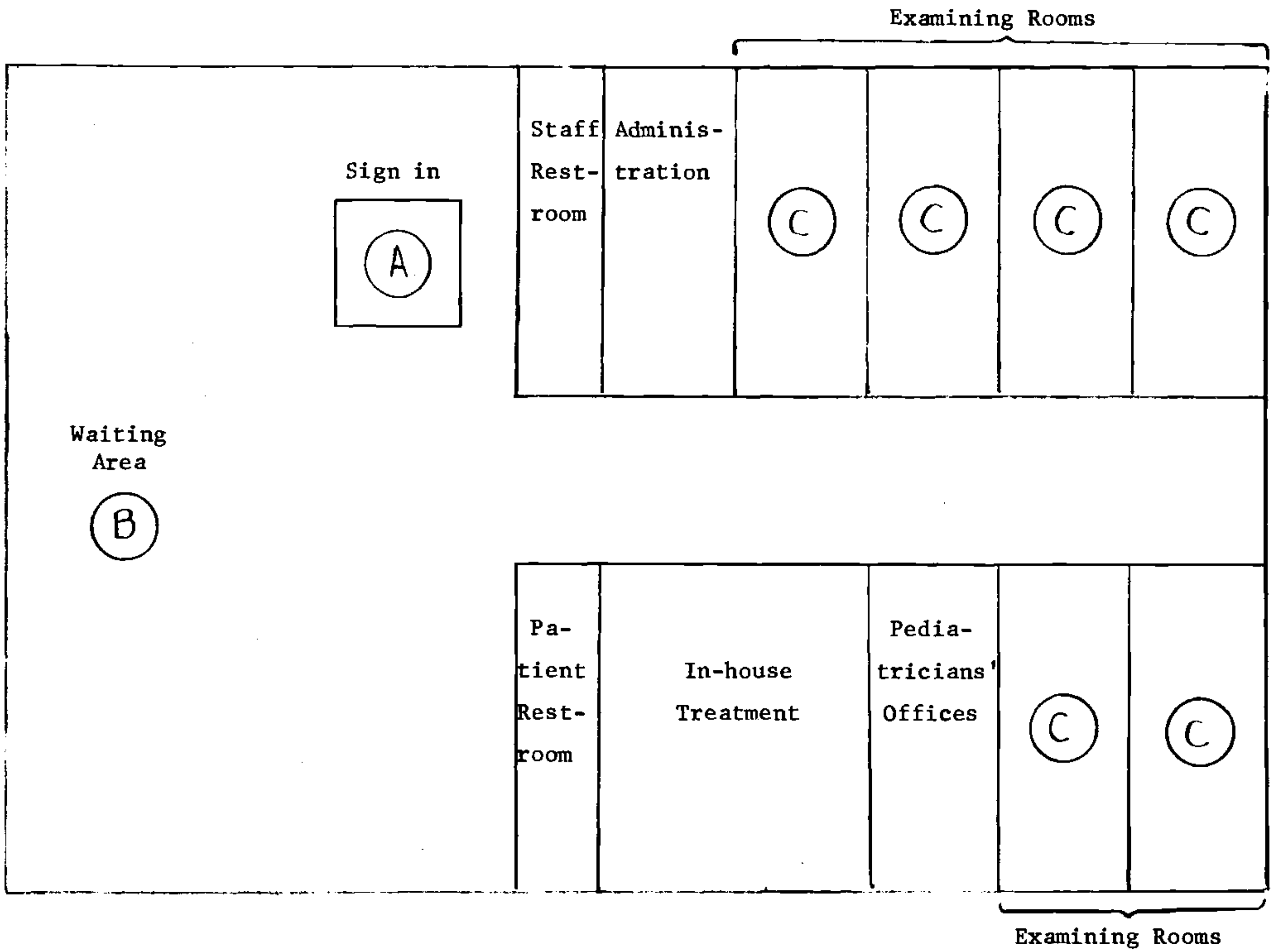


Figure 3. Pediatric Clinic Layout

wait in the main waiting area B and are called forward to the examining rooms C as they become available. They are called forward on a first-come-first-served basis within priority groups. Each pediatrician alternates between two examining rooms.

Consultations take place in the examining rooms. Upon completion of a consultation, one of several dispositions is directed:

1. Patient may depart the clinic.

2. Patient may depart the clinic via the in-house treatment facility.

3. Patient may go to the laboratory.

4. Patient may go to the x-ray facility.

If either disposition four or five is directed, the patient proceeds to the appropriate facility outside the pediatric clinic. When the necessary tests have been completed at that station, the patient returns to the pediatric clinic waiting area B . In the case of laboratory tests, the patient waits until the results of those tests are called to the clinic. At that time the patient is given a higher priority (return) and is called for a reconsultation on a first-come-first-served basis within the new priority group. Patients who go to the x-ray facility are required to wait there until the film is processed. The processed film is then hand carried back to the clinic by the patient. Upon re-entering the waiting area B , he is given the return priority and is processed in the same manner as described above. After completing the reconsultation, these patients may either make a direct departure or leave via the in-house treatment station. It should perhaps be noted that the term direct departure does not necessarily imply that a patient leaves the hospital complex.

A patient may, for example, be admitted as an inpatient to the appropriate ward. A patient so classified does, however, make a direct departure from the system described in this study since no further demand is made on the services which are provided within the system.

Walk-in patients who are given the emergency classification follow the same general pattern of flow that was described above; however, several differences exist since every effort is made to expedite the delivery of services to these patients. Emergency patients bypass records acquisition and report directly to the pediatric clinic. The arrival of an emergency patient causes one pediatrician to interrupt whatever service is being administered at the time, and he directs his attention immediately to the emergency patient. Any subsequent treatment within the clinic is also provided on the same basis.

Data Collection

An early step in the analysis was the identification of a need to collect data within the existing system so that system parameters could be characterized. After the initial meeting with the clinic staff and preliminary observation of the system, it became obvious that the data collection effort would have to be designed so that interference with the normal system operation would be minimal. This was necessary for two reasons:

1. So that the data would accurately reflect the true characteristics of the system.

2. So that the participation of clinic personnel would not detract from the performance of their primary duties.

Three methods of data collection were employed in the conduct of the study. The first was direct observation of an activity or sequence of activities which could be observed from one position. All arrival time data and some service time data were collected in this manner. The process of collecting data by this method consists of observing events that occur at a point in the system and transcribing the appropriate entry onto a data sheet. This is not a difficult operation; hence, it does not require trained personnel. During a portion of the data collection period, the author was assisted in this effort by ambulatory active-duty inpatients. A short briefing prior to a period of data collection was sufficient in most cases to insure the proper accomplishment of the task.

The second method of data collection was basically the same as that described above; the difference was that these data were collected by clinic personnel. The advantages of utilizing clinic personnel to assist in data collection are obvious. First, there is less of a tendency to depart from the regular work pace because of the presence of outsiders. Another advantage is that fewer additional personnel are needed to collect data. Finally, there is the matter of professional ethics. In the collection of pediatrician service time data, there was a reluctance on the part of the pediatricians to permit non-clinic personnel to be present during patient consultations. Hence, the use of clinic personnel to assist in the collection of those data overcame a potential problem. The disadvantages of this method are twofold:

1. Since this effort is not the primary duty of clinic personnel, there is a tendency to overlook data collection, especially when the clinic is quite busy. Hence, periodic checks are necessary to insure that the

data are being collected properly.

2. There is some degree of interaction between the collection of data and the normal accomplishment of the primary duty of the personnel involved. Though this represents a potential problem in general, its effect on the collection effort associated with this study was found to be negligible.

Data were also collected through the use of a printed form. A sample form is shown in Figure 4. This form was attached to the medical record of each scheduled or walk-in patient during his processing at the sign-in desk and was carried by the patient as he progressed through the system. Patients were not permitted to make entries on the form. The same advantages and disadvantages accrue to this method as were noted for the previous method. An additional disadvantage was that some patients lost the form during their progress through the clinic. Hence, additional sampling was necessary by direct observation as a check on the data gathered in this manner.

During the conduct of the study, all time data were collected to the nearest whole minute. An initial attempt to collect these data in smaller units proved to be infeasible due to the burden imposed upon those clinic personnel who assisted in the collection effort. Although more precise estimates of system parameters could have been made if smaller time units had been used, the accompanying undesirable effect upon the normal progress of clinic activity was considered to more than offset the benefit which might have resulted from the increased precision of the estimates of system parameters.

PRIORITY: ______ Emergency
______ Appointment
______ Recheck
______ Routine

SPECIFIC DOCTOR REQUESTED?
______ Yes
______ No

SIGN-IN DESK: Arrive ______
Depart ______

CONSULTATION WITH DOCTOR: Begin ______
End ______

DISPOSITION: ______ In-house ______ Lab
______ Departure ______ X-Ray

FINAL DOCTOR CONSULTATION: Begin ______
End ______

FINAL DISPOSITION: ______ Depart ______ In-house
______ Lab ______ Other

Figure 4. Data Collection Form (Patient)

Data collection was accomplished during two periods. The first was a two week period during the month of February, the month in which hospital officials anticipated the highest level of patient input. The second was a four week period during June and July, a period during which the clinic had historically experienced its lowest level of patient input.

Two broad classes of probability distributions must be described in the study of any queuing system. These are the distributions of inter-arrival times for units entering the system and the distributions of service times for the various service facilities within the system. The process of defining these classes of probability distributions was accomplished in basically the same manner. First, the appropriate data were collected. These data were then summarized in the form of frequency distributions. At this point in the process a guess was made about the form of the distribution; i.e., it was hypothesized that the distribution of the variable under consideration followed some known distribution. Once the form of the distribution had been hypothesized, its parameters were estimated. Finally, the data were compared with the hypothesized distribution to determine whether the particular distribution selected adequately characterized the random variable under consideration.

Five different arrival distributions were identified for the purposes of this study:

1. Pediatric arrivals on MTTHF (Monday, Tuesday, Thursday, and Friday).

2. Pediatric arrivals on Wednesday afternoon.

3. In-house only arrivals.

4. Non-pediatric arrivals at the records room.

5. Non-pediatric arrivals at the x-ray facility.

In applying the process noted above to the study of these distributions, data were collected for each of the categories of patient arrivals. The time of each arrival was noted on a data collection sheet. From these raw data the numbers of arrivals during intervals of a fixed length were easily computed. Because of the nature and large size of the calling population (patients eligible for the services provided in the system), stability and statistical independence were assumed. However, investigation of the daily patterns of arrivals led to the conclusion that a relationship existed between the mean arrival time and the time of day in each of the distributions under consideration. Since there were a large number of chance factors which had an influence upon the patient arrival times, it was hypothesized that the interarrival times were exponentially distributed with a mean which varied according to the time of day. An estimate of the mean at any point in time required the observation of a large number of arrivals in an interval of time surrounding that point; hence, a procedure was needed which would negate the need for a massive data collection effort while providing an adequate description of the behavior of the mean.

To examine how this was accomplished, consider as an example the distribution of pediatric arrivals on MTTHF at the records room. Initially, the day was divided into thirty minute intervals, and the number of arrivals in each interval was plotted on a time scale. The general behavior of the mean rate of patient arrivals was evident from an examination of this graphical device. The rate of arrivals rose from an initial value at the time of clinic opening (7:30 a.m.) and peaked between 8:45 a.m. and 9:45 a.m. The rate dropped until noon, then increased again to a second, but lower, peak in the interval 1:00 p.m. to 1:30 p.m. From this peak the rate showed a steady decline until the closing time (3:30 p.m.). Due to the need for computational efficiency and the generally steady rates of increase or decrease between the inflection points on the curve, it was decided that the curve could be adequately described by obtaining good point estimates of the parameter value at the inflection points and assuming that the mean varied linearly between each set of points. The procedure used to determine the value of the parameter at the inflection points was a technique described by Hines [22]. For example, consider the value of the parameter at 9:15 a.m. An interval (8:45 - 9:45) was constructed around this point. An estimate of the mean rate of arrivals, $\hat{\lambda}$, was obtained by dividing the total number of arrivals by the total time of the 361 observed arrivals.

$$\hat{\lambda} = \frac{361 \text{ arrivals}}{104 \text{ intervals} \times 15 \text{ minute/interval}}$$

$$= .231 \text{ arrivals/minute}$$

It can be shown that this estimator is unbiased, consistent, and a maximum likelihood estimator [22, p. 177]. If the arrivals are indeed random, i.e., if the interarrival times are exponentially distributed, the probability that n arrivals will occur in a fixed interval of length t will follow the Poisson distribution.* The theoretical frequency of

*This relationship between the Poisson and exponential distributions is well known. Further discussion of the principles involved can be seen in references 22 and 23.

arrivals for the Poisson distribution can be easily computed, and the hypothesis that the distribution of arrivals in this interval follows the Poisson distribution can be tested by comparing the observed frequencies of arrivals to the theoretical frequencies for a Poisson distribution with parameter λ. The calculations described above are shown in Table 1. Table 2 shows the application of a Chi-square Goodness of Fit Test to the hypothesis. The hypothesis could not be rejected at the five percent level of significance. Point estimates of the parameter value at other time points were obtained in a similar manner. The resulting behavior of λ for the arrival distributions is shown in Figures 5 and 6.

Service time data were collected by all of the methods described earlier. The basic process of describing the various service time distributions was identical except that no relationship was noted between the mean service time and the time of day. The distributions of service times for the functions performed in the system are shown in Table 3. Hypotheses with respect to these distributions were tested successfully at the five percent level of significance. The service times for records acquisition were found to be exponentially distributed. Parameter estimation and hypothesis testing followed the procedure used above for arrival distributions. The distribution of service times for walk-in patients was found to be Erlang or hypoexponential. An estimate of the mean service time, $\hat{\theta}$, was obtained which had the same properties noted above for the mean arrival rates. An initial attempt to fit the observed data to an exponential distribution failed. Since the observed data showed less variability than the exponential distribution, it was decided to attempt to fit an Erlang distribution. Trial values of k were selected and a good

Table 1. Summary of Pediatric Arrivals (8:45 - 9:45)

(1) Number of Arrivals During 15-Minute Interval	(2) Frequency of Intervals Having Number in Column (1)	(3) Number ≧ Value in Column (1)	(4) Total Number of Arrivals (4) = (1) X (2)
0	2	104	0
1	13	102	13
2	16	89	32
3	21	73	63
4	24	52	96
5	17	28	85
6	6	11	36
7	4	5	28
8	1	1	8
TOTAL	104		361

Table 2. Chi-Square Goodness of Fit Test

Number of Arrivals in 15 Minutes	Observed Frequency (O_i)	Theoretical Frequency (E_i)	$\frac{[O_i - E_i]^2}{E_i}$
0	2	3.23	.4683
1	13	11.22	.2823
2	16	19.47	.6184
3	21	22.53	.1039
4	24	19.55	1.0129
5	17	13.57	.8670
6	6	7.85	.4359
7	4 } 5	6.58	.3794
8	1		
		Total	4.1681

$$\sum_i \frac{[O_i - E_i]^2}{E_i} = 4.1681 < \chi^2_{.05,7} = 14.07$$

Accept H_0: Time Between Arrivals ~ Exponential (λ = .231)

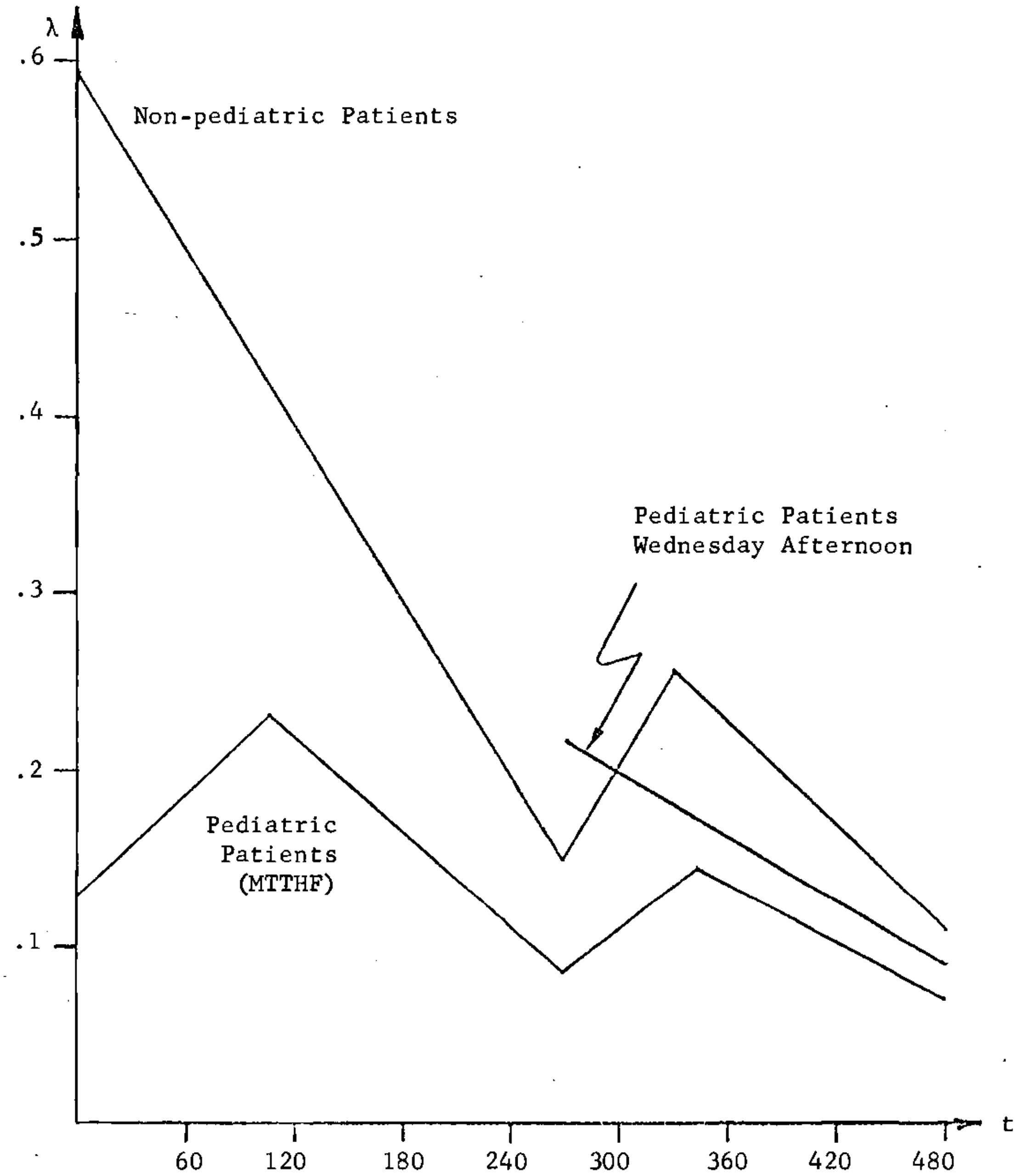


Figure 5. Behavior of Mean Rate of Arrivals at Records Room

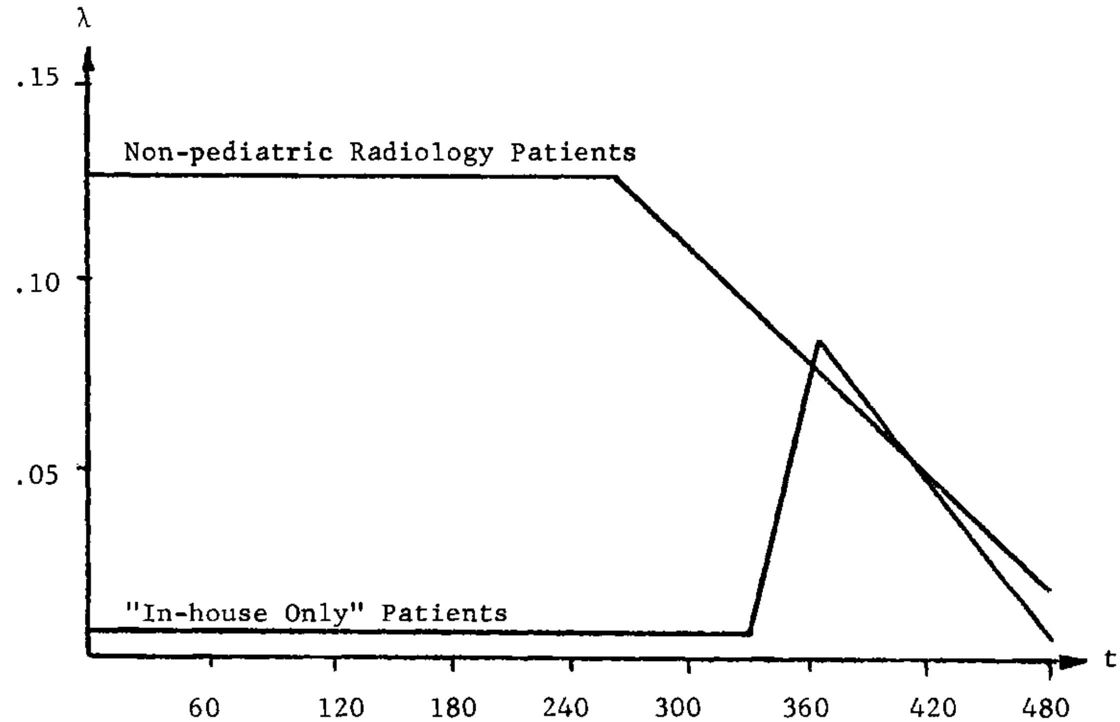


Figure 6. Behavior of Mean Rate of Arrivals at In-house Treatment and Radiology

Table 3. Service Time Distributions

Pediatrician	
Walk-in Examination	Erlang ($k = 2$; $\mu = .124$)
Well-baby Examination	Normal ($\mu = 9.043$; $\sigma^2 = 1.862$)
Physical Examination	Normal ($\mu = 11.912$; $\sigma^2 = 4.933$)
In-house Treatment	Erlang ($k = 4$; $\mu = .199$)
Records Acquisition	Exponential ($\mu = .485$)
X-Ray	Erlang ($k = 4$; $\mu = .190$)
Laboratory (total time absent from pediatric clinic)	Normal ($\mu = 72.24$; $\sigma^2 = 811.78$)
Nursery Check (total time absent from pediatric clinic)	Normal ($\mu = 50.76$; $\sigma^2 = 444.27$)

fit was obtained for k = 2. The distributions of service times for in-house treatment and x-ray service were also found to be Erlang. The parameters for these distributions were estimated in the same manner. The examination times for well-baby and physical examination patients were found to be normally distributed. The well known estimators $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ and $s = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}$ were used to estimate the means and variances of these distributions as well as for the two normal distributions which follow.

The last two distributions listed in Table 3 are not service time distributions in the usual sense of the term. However, because of the approach used in modeling these operations, they were treated as such for hypothesis testing. Both the time spent away from the pediatric clinic by the pediatrician making the daily nursery check and the time spent away from the clinic by patients obtaining laboratory services were found to be normally distributed.

It was also necessary to collect data for the description of patient characteristics and routing probabilities within the system. Data for estimating these probabilities were obtained by the methods described earlier in this chapter. Estimates regarding patient characteristics were obtained by dividing the number of patients who possessed a certain characteristic by the total number of patients who were observed in the sample taken for that purpose. For example, in a sample of 401 walk-in patients, six were given the emergency classification; hence, the estimate of the fraction of walk-in patients who are classified as emergency cases was $\frac{6}{401} = .015$ or 1.5 percent. Estimates of routing probabilities were obtained similarly. For example, the fraction of patients who make a direct departure from the system upon completion of consultation with a pediatrician was $\frac{110}{211} = .521$ or 52.1 percent; hence, this figure became the estimate of the probability of occurrence of that event.

Model Synthesis

The philosophy and general approach to modeling in this study are described in Chapter I. The system was modeled for computer simulation using a general purpose simulation language, General Purpose System Simulator II (GPSS II). GPSS II is basically a transaction-flow language; hence, it is well suited for the purposes of this study. A detailed description of the language and its characteristics can be found in reference 24. A flow diagram of the basic program which was developed is shown in Appendix I. A compilation of this program which lists the GPSS II statements necessary for implementation is shown in Appendix II. The program was processed on a UNIVAC 1108 model computer. An average run time of approximately 14 seconds was experienced for the simulation of one day of clinic operation. Output from the program included the compilation of statistics for the measures of system effectiveness. These were the total time spent in the system for walk-in and scheduled patients, the utilizations of each service facility within the system, and the clinic closing time. Many other statistics not referenced directly in this study were also collected by the program.

A time interval of one simulator clock unit for each .01 minute of real system time was selected for running the simulation model. Though no additional accuracy was obtained due to the fact that data were accurate only to the nearest whole minute, the smaller simulator time units were necessary to insure that truncation inherent in the GPSS II system computations would not adversely affect the simulation.

A simplified GPSS flow diagram which depicts the basic characteristics of the model is shown in Figure 7. Walk-in patient generators which are represented by single blocks in Figure 7 were composed of a segment of four blocks which act together to generate flow units according to the exponential distributions identified during the data collection process. In the segment shown in Figure 8, block 17 creates a flow unit (transaction) which immediately enters block 18. This block then refuses entry to any other transaction until the unit currently being processed in the segment of blocks 18, 19, and 20 exits block 20. The transaction moves immediately to block 19 which evaluates function 19 and assigns the value of that function (mean time between arrivals as a function of clock time) to position 11 in the parameter field of the transaction. Then the transaction is held in block 19 for a period of clock time equal to the product of the value in parameter 11 and a value obtained by evaluating function 20 (the exponential distribution). When this period of simulation time has elapsed, the transaction moves through block 20 and into the system, and another transaction enters block 18 to begin the cycle. The output from this pseudo-generator accurately represents walk-in patients entering the system with an exponential interarrival time distribution having a variable mean.

Simulating the arrivals of scheduled patients was less complicated.

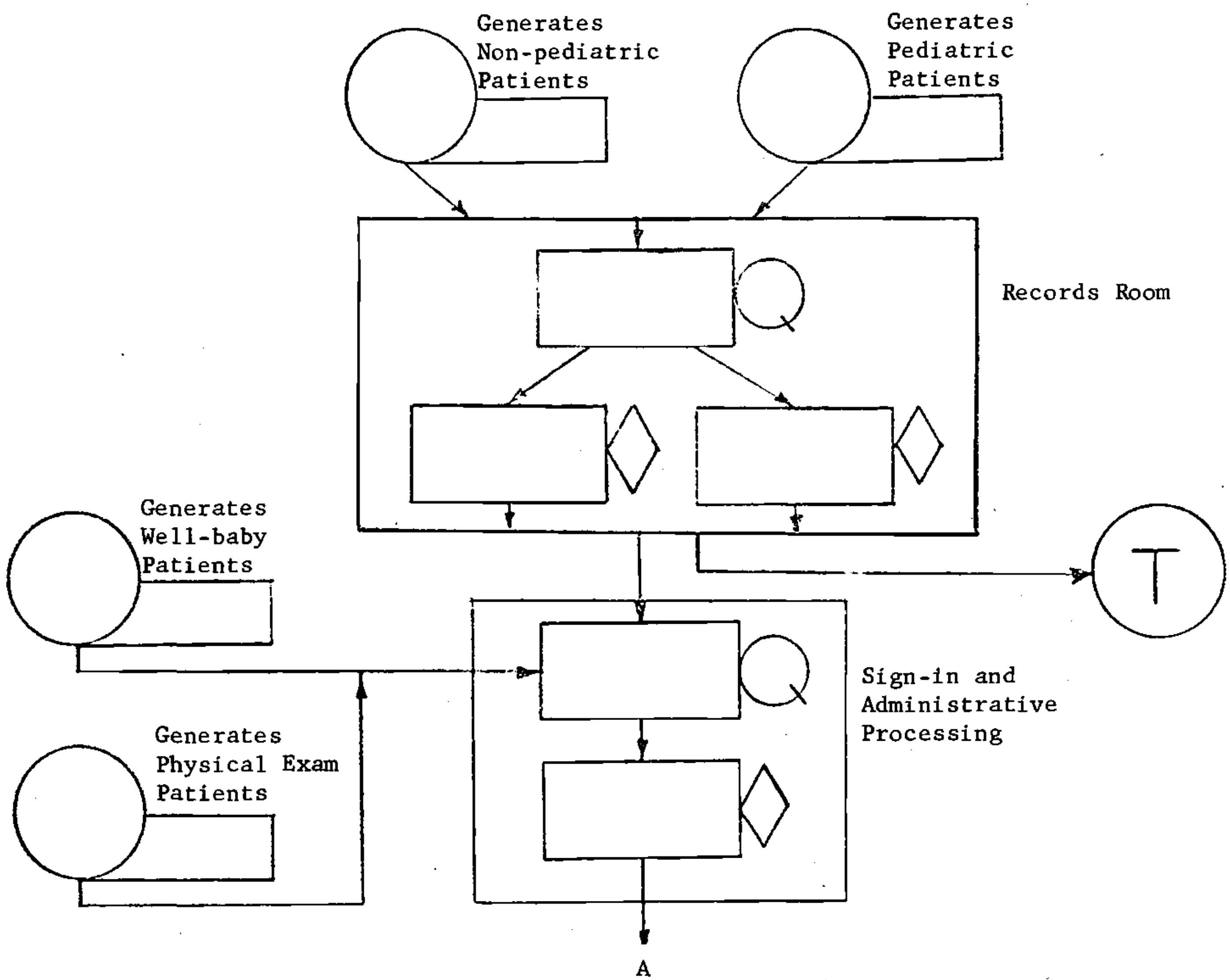


Figure 7. Simplified GPSS Flow Diagram of Pediatric Clinic and Adjunct Facilities

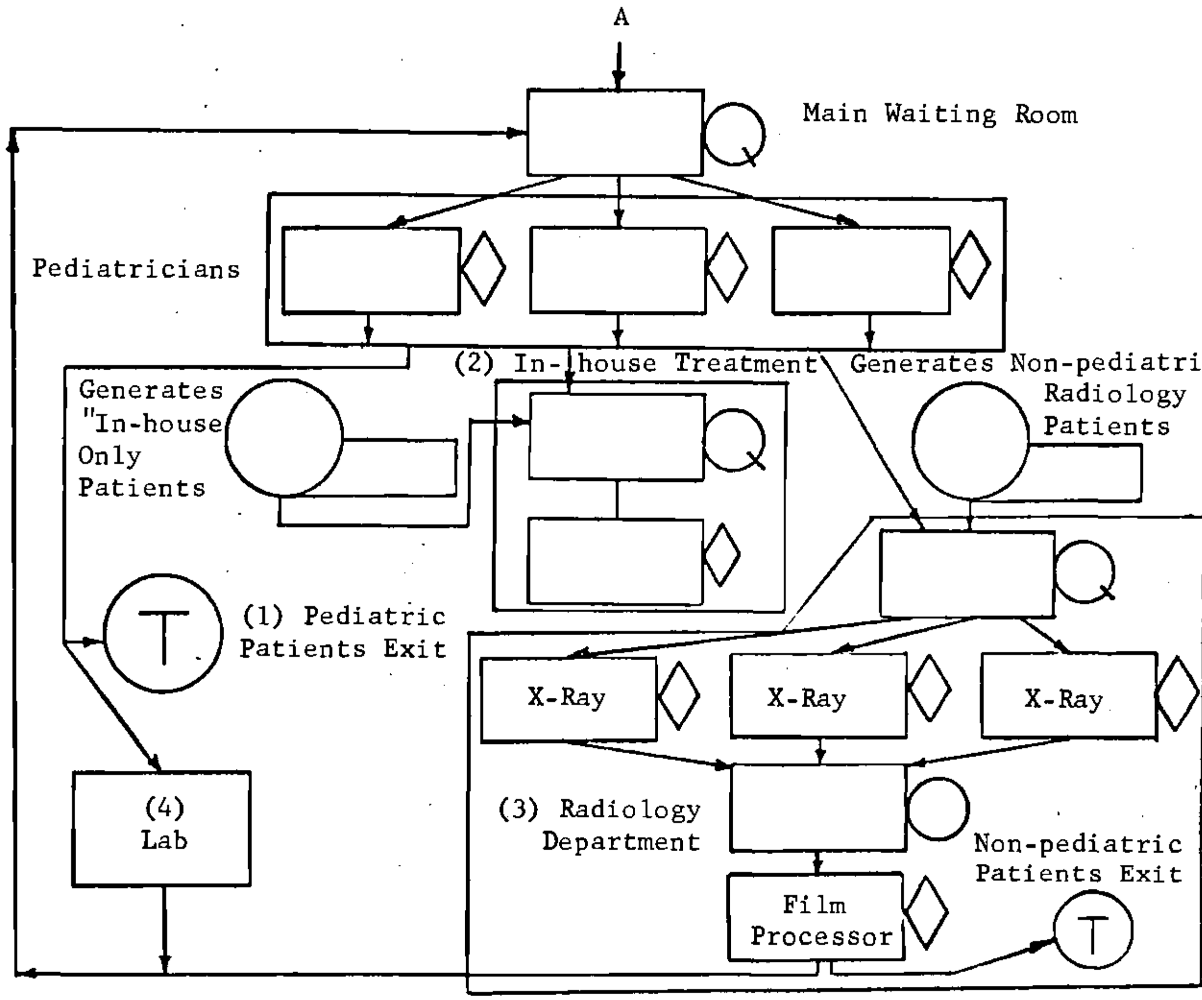


Figure 7. Continued

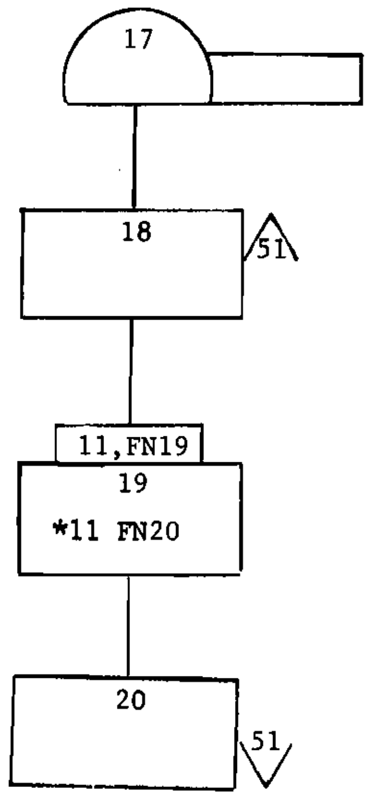


Figure 8. Pseudo-generator

Transactions representing these patients were generated directly into the system at their scheduled times of arrival. By so doing, the model implicitly assumes that scheduled patients are punctual. This assumption was felt to be justified in this study for two reasons:

1. Scheduled patients represented only a small percentage of the total patient load.

2. The main thrust of the study was toward the analysis of the characteristics of services rendered to walk-in patients.

Each transaction which is generated is assigned a priority in accordance with the probabilities developed during data collection. In addition, each transaction has assigned to its parameter field certain numbers or variables which identify such characteristics as patient category, classifications within categories, and physician preferences. These parameter values and priorities are accessed at various points in the model to determine the route a particular transaction will take through the system, order of entry into facilities, and the time spent in obtaining services at different facilities.

Transactions in the system progress from block to block within the model just as patients move within the real system. The transactions wait in queue blocks until the facility to which they are directed is vacated. The queue discipline in the simulation model is FIFO (first-in-first-out) within assigned priority groups for all transactions except those which represent emergency patients. These transactions interrupt facilities which are providing services to other types of transactions in the same manner that emergency patients interrupt the normal flow of services in the real system.

The service time distributions which were identified during data collection are represented by functions in the program. When a transaction enters a block which represents a service facility, one of these functions is evaluated to determine the amount of simulation time which the transaction will spend in the block.

When a transaction departs one of the blocks which represents a pediatrician consultation, it is directed to either (1), (2), (3), or (4) (see Figure 7), according to the routing probabilities associated with the type of patient it represents. Transactions entering (1) exit the system. Those units which enter (2) compete for service in that segment of blocks with transactions representing in-house only patients before exiting the system. Transactions which are routed to the chain of blocks in (3) compete with units generated in P to enter one of the blocks representing x-ray rooms; then they compete again to enter the block which represents the film processor. When a transaction departs segment (3), it is rerouted to the main waiting room queue to wait for and obtain re-entry to the block representing the pediatrician who requested the x-ray.

The process of obtaining services in the medical laboratory was modeled in a different manner. Because of the complexity of the operation of the laboratory, modeling the process of obtaining the many and varied services offered therein would have been an extremely time consuming activity; it would have required the description of numerous service time distributions. Hence, this process was modeled as a single service facility with unlimited capacity within which transactions were held during program execution according to a service time distribution which was developed for this purpose. This distribution described the period which elapsed from the time a patient was referred to the laboratory until the appropriate test results were made available to the pediatric clinic. Thus the laboratory was treated as a "black box." No information was gained about that which transpired inside; however, since an analysis of the laboratory was not an objective of the study, this technique provided an adequate description of the process without the necessity of a massive data collection and analysis effort within the laboratory.

Periods of unavailability for service facilities were modeled through the use of time keeping transactions. These transactions were generated at the appropriate times to enter and occupy the facilities, thus rendering them unavailable for normal activity, for the necessary interval of time. Such activities as the absence of a pediatrician for nursery check, lunch breaks, and coffee breaks as well as the unavailability of x-ray rooms during certain periods of the day were modeled in this manner. Detailed GPSS block diagrams of several of these program segments are shown in Figure 9.

During both of the data collection periods, the pediatric clinic was involved in staff transition with the number of pediatricians present in the clinic varying from day to day and even during the course of a day as newly assigned pediatricians settled into the clinic routine and departing staff members prepared for their termination of service. Since the system was in a state of transition during these periods, it was not possible to collect data which would permit a meaningful quantitative validation of the model. However, inspection of the results of check runs of the completed model by the author and by experienced hospital management personnel indicated that the model adequately represented the system.

This segment sends the pediatricians to lunch.

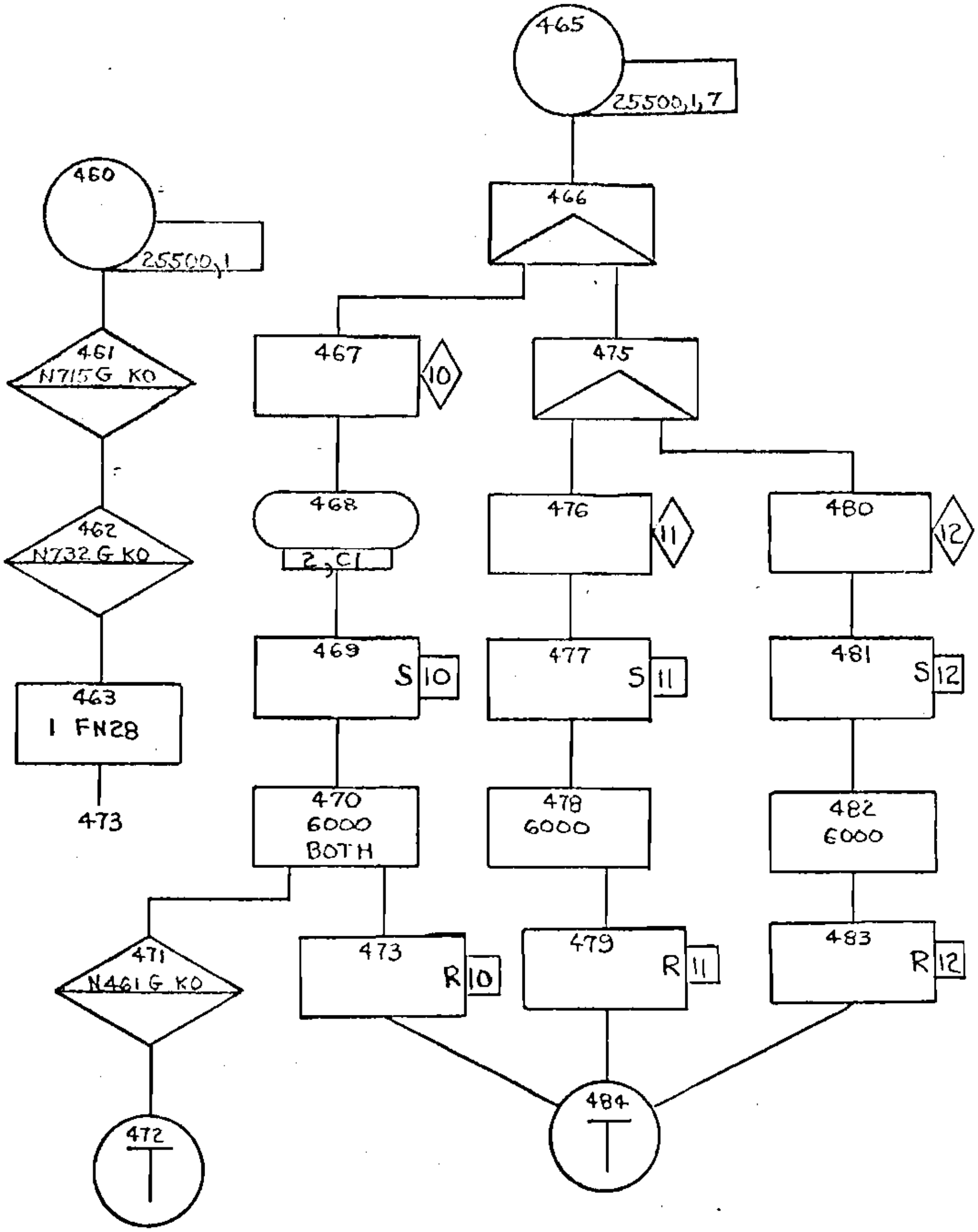


Figure 9. Detailed GPSS Flow Diagram of Miscellaneous Program Segments

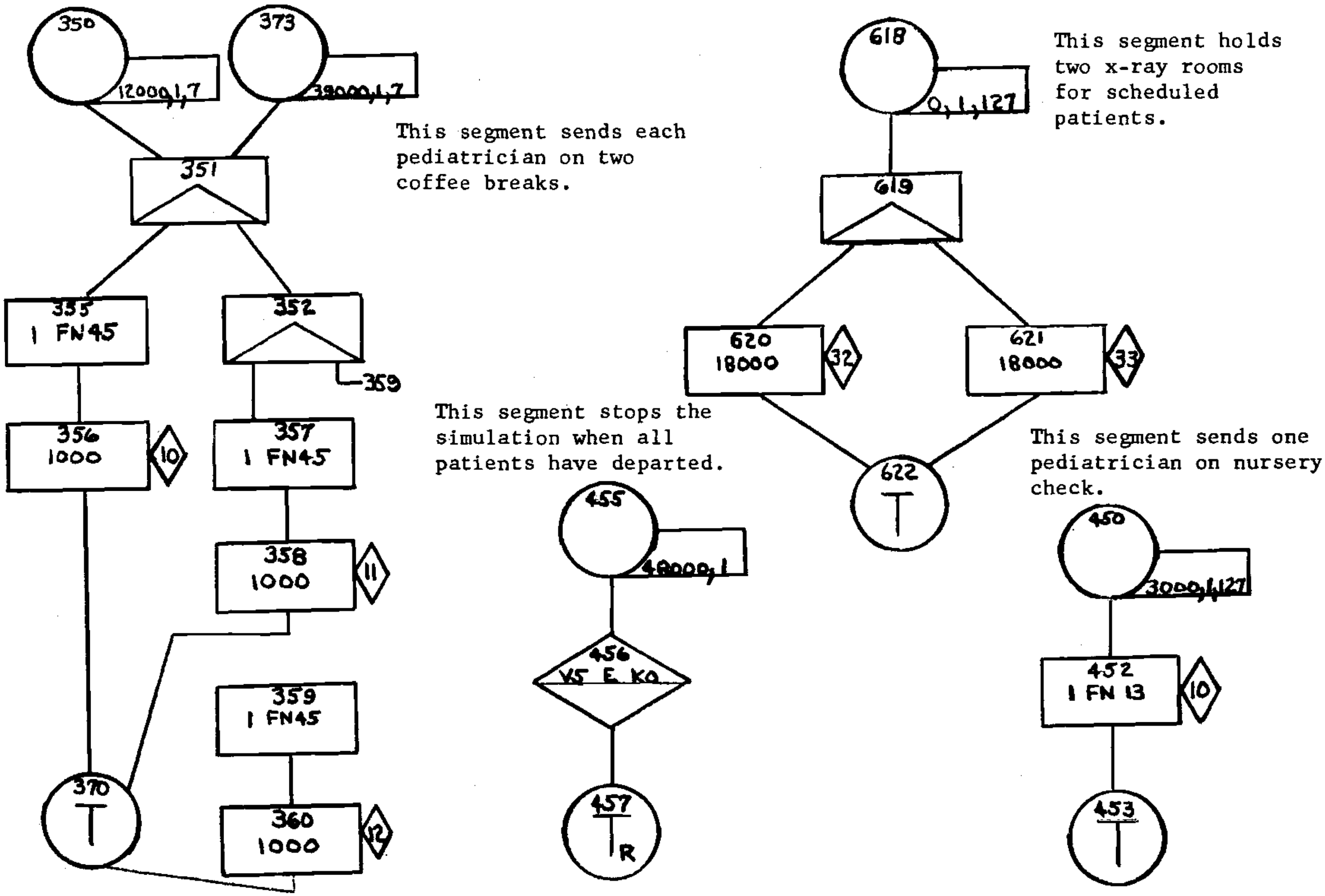


Figure 9. Continued

CHAPTER IV

EXPERIMENTAL DESIGN AND RESULTS

Experiment

There were three general considerations which motivated the design of this experiment. First, an experiment was needed which would permit the prediction of the probable performance of the system under the operating conditions of interest. Second, it was desirable to have an experimental design which would allow an assessment of the changes that occur in the response as one or more of several factors are varied. Finally, an experiment was needed which would permit the statistical evaluation of an alternative to the existing operating policies within the clinic.

After consultation with hospital officials, it was determined that the dominant response for purposes of decision making would be the time spent by pediatric walk-in patients in obtaining medical services within the system. Since this category of patients was not deemed to be subject to scheduling and since it was the policy of the pediatric clinic to provide medical services to all such patients on the day that these services were demanded, other measures of effectiveness were considered to be of secondary importance.

Consequently, a decision was made to base the analysis primarily upon the time spent by walk-in patients in obtaining medical services in the system. However, it was considered necessary to provide data concerning the time spent by scheduled patients in obtaining medical services, the utilization of pediatricians, and the duration of clinic operation for consideration by the decision maker. The underlying philosophy was that if these three measures of effectiveness were within "acceptable" limits, then the decision maker would be able to base his analysis upon the primary measure of effectiveness. In cases where one or more of these values fell outside a reasonable range, the decision making process would presumably be dependent upon some qualitative combination of all four of the measures of effectiveness. It should perhaps be pointed out that if the relative values of these measures of effectiveness could be quantified along with the cost of different levels of staffing, choices between alternatives could be made on a quantitative basis; however, since hospital officials were unwilling to weight the different measures of effectiveness, no attempt was made to incorporate this type of analysis procedure into the study. Instead, it was decided to base the analysis upon the primary system response while providing data concerning the other responses in tabular form for consideration by the decision maker.

Three system parameters which had been identified during the course of the study were selected for variation in the experiment. These were the number of pediatricians in the clinic (N), the level of patient input (I), and the type of day(D). Three levels of N (two, three, and four pediatricians) were considered since these were the numbers of pediatricians which the hospital might reasonably expect to have made available by higher authorities in the foreseeable future. Four levels of patient input were considered:

1. Present summer input.

2. A 25 percent increase to summer input.

3. Present winter input.

4. A 25 percent increase to winter input.

Levels two and four were selected by hospital management officials based on projected increases to current input. Examination of recent historical records of patient input and the results of data collection during both summer and winter input conditions led to the conclusion that peak winter input could be considered to be 40 percent greater than summer input. Hence, four quantitative levels of input were obtained. Since clinic operating policies considered two types of days (MTTHF and Wednesday), it was necessary to consider D at two qualitative levels.

During the course of preliminary analysis of the system, an alternate set of operating policies was developed for the clinic which, it was felt, might increase the effectiveness of clinic operation. Hence, a fourth factor, the clinic operating policies (S), was included in the experiment. During the periods of preliminary observation of the system and data collection, it was noted that under existing clinic policies scheduled patients were injected into the system on MTTHF during the period of peak walk-in patient input. In addition, since four to six patients were given the same appointment time, the input of scheduled patients occurred in blocks. It seemed reasonable to hypothesize that as a result of these policies, the patient waiting times and hence the time spent in the system were at an unnecessarily high level. Furthermore, two observations were made concerning the operating policies on Wednesday. First, it appeared that the clinic was operating at far too small a patient load on

Wednesdays, especially during the winter season. Even with only two pediatricians on duty in the clinic, less than half of the available pediatrician time was scheduled for examinations. Since the patient input was subject to scheduling on Wednesday mornings, the results of the literature survey seemed to indicate that the policy of scheduling appointments in blocks of up to eight patients simultaneously might be unnecessarily inflating the time spent in obtaining medical services.

The alternate set of policies was developed for the purpose of attempting to correct whatever undesirable effects these aspects of the existing policies might have upon the time spent in obtaining medical services within the system. Salient features of the alternate set of policies which was developed were as follows:

1. Where sufficient pediatrician time was available, all patients scheduled during a week were given appointments on Wednesday morning. It was felt that the benefits of this change would be twofold. First, more effective use would be made of pediatrician time on Wednesday morning while removing a potential source of additional waiting for MTTHF walk-in patients. Second, this change had the desirable effect of negating the need to expose well-baby patients currently being examined on MTTHF to the possible ill effects of having to sit in the waiting room with sick children on those days.

2. Where conditions of patient input and the number of pediatricians in the clinic made the movement of all MTTHF scheduled patients to Wednesday morning impossible due to an insufficient amount of pediatrician time on that day as many scheduled patients were shifted to Wednesday as

pediatrician time would allow, and the remaining MTTHF scheduled patients were given appointments during periods of lower demand on MTTHF, e.g. during the late morning and mid-to-late afternoon.

3. Block scheduling of appointments was abandoned in favor of an individualized system of appointments. The general rule of the new system was to schedule patients individually at intervals equal to the mean service time for the particular classification of patients. The development of this rule represented an attempt to make use of a technique which was widely advocated for scheduled clinics in the literature (see Chapter II). The anticipated result of this change is aptly stated by Johnson and Rosenfield. "Any appointment system that provides for staggered arrivals of patients, whether on an individual or time wave basis, has the effect of reducing patient waiting time..."[25] Besides the expected reduction in waiting time for scheduled patients, it was anticipated that the Wednesday morning scheduled sessions would be shortened as a result of the individualized appointment system. This would permit the Wednesday afternoon walk-in sessions to begin earlier. It was expected that this would have the effect of reducing the time spent in obtaining medical services by Wednesday afternoon walk-in patients.

A completely randomized factorial experiment was selected. Each of the four factors (N, I, D, and S) was considered at the number of levels discussed above. Hence, the experiment consisted of 48 different experimental conditions ($3 \times 4 \times 2 \times 2$). Preliminary observation of the existing system indicated that considerable variability could be expected under the same set of experimental conditions; hence, it was decided that three observations would be taken under each of the 48 experimental conditions. This resulted in a total of 144 simulation runs. Each run simulated a full day of system operation. In order to completely randomize the 144 observations, a different random number seed was selected for each run from a table of random numbers.

The mathematical model for this experiment and design was

$$Y_{ijklm} = \mu + N_i + I_j + NI_{ij} + D_k + ND_{ik} + ID_{jk} + NID_{ijk} + S_{l(ijk)} + \epsilon_{m(ijkl)}$$

where

Y_{ijklm} represents the response (mean time spent by pediatric walk-in patients in obtaining medical services within the system)

μ represents a common effect for the experiment

N_i represents the number of pediatricians in the system where $i = 2, 3,$ and 4

I_j stands for the input level where $j = 1, 2, 3,$ and 4

D_k represents the day type where $k = 1$ and 2

$S_{l(ijk)}$ stands for the alternative sets of operating policies where $l = 1$ and 2

$\epsilon_{m(ijkl)}$ represents the random error in the experiment where $m = 1, 2,$ and 3

The other terms denote the interactions between the factors N, I, and D.

Analysis of Results

The results of the experiment are given in Appendix III. Table 9 of this appendix shows the system response in terms of the primary measure of system effectiveness, the mean time spent in obtaining medical services for pediatric walk-in patients. Point estimates of this measure of effectiveness for each of the 48 experimental conditions were obtained by taking the sample mean of the three observations which had been taken under these conditions:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

where

x_i represents the response based upon the simulation of a full day of system operation, i = 1, 2, and 3

n represents the number of observations in the sample (n = 3)

The sample mean, $\bar{x}$, is an unbiased and consistent estimator of the true mean of the population. The values of these estimates are shown in Table 4. Point estimates of the mean time spent by scheduled patients in obtaining medical services and the average utilization of pediatricians were computed in the same manner and are shown in Table 5 and Table 6, respectively.

A four-way Analysis of Variance (ANOVA) was conducted for the primary measure of effectiveness data shown in Table 9 of Appendix III. The ANOVA is summarized in Table 7. In applying the ANOVA to these data, it was assumed that μ was a fixed constant and that the errors were independent and normally distributed with common variance. Since the levels of each factor in the model were fixed, the tests for significance were straight-forward. All tests were made by using the error mean square in

Table 4. Mean Time Spent by Pediatric Walk-In Patients in Obtaining Medical Services

Number of Pediatricians	Present Summer Input Level		Present Winter Input Level		25% Increase To Summer Input		25% Increase To Winter Input		
	M	W	M	W	M	W	M	W	
2	64.13	46.99	95.08	54.44	95.46	50.12	117.06	85.43	
3	30.78	32.24	43.36	35.01	40.36	39.38	57.67	50.59	Present Policies
4	28.35	26.12	32.04	32.94	26.52	32.56	35.84	35.89	
2	31.96	47.70	60.07	30.08	52.91	49.69	94.45	73.30	
3	24.14	22.29	34.41	21.74	30.15	40.09	41.67	28.28	Suggested Policies
4	23.69	19.64	27.02	25.61	24.69	21.25	32.20	19.07	

Table 5. Mean Time Spent in Obtaining Medical Services for Scheduled (Well-Baby and Routine Physical) Patients

Number of Pediatricians	Present Summer Input Level		Present Winter Input Level		25% Increase To Summer Input		25% Increase To Winter Input		
	M	W	M	W	M	W	M	W	
2	30.58	24.57	25.54	25.11	28.14	26.28	30.89	31.76	
3	23.00	18.78	16.39	18.50	22.58	21.35	20.57	22.93	Present Policies
4	18.52	15.65	22.32	15.91	16.65	19.09	20.42	19.64	
2	13.25	18.11	N/A	15.72	22.43	15.92	N/A	17.45	
3	N/A	15.27	N/A	11.32	N/A	15.92	N/A	**13.91**	Suggested Policies
4	N/A	13.67	N/A	10.94	N/A	14.25	N/A	12.24	

Table 6. Average Utilization of Pediatricians

Number of Pediatricians	Present Summer Input Level		Present Winter Input Level		25% Increase To Summer Input		25% Increase To Winter Input		
	M	W	M	W	M	W	M	W	
2	80.42	55.69	96.83	73.71	95.60	74.26	96.95	80.14	Present Policies
3	51.02	32.51	71.16	43.14	66.27	61.86	82.09	55.35	
4	34.58	24.00	53.98	37.25	48.64	38.66	63.35	42.56	
2	63.13	78.22	90.94	81.02	91.55	80.09	95.53	90.29	Suggested Policies
3	40.02	64.17	66.24	53.12	58.02	71.26	74.44	65.99	
4	31.25	46.86	40.96	42.31	37.90	57.45	58.42	46.93	

Table 7. ANOVA for Time Spent in Obtaining Medical Services for Pediatric Walk-in Patients

Source	SS	df	MS	F	$F_{.01}$	
N	38465.59	2	19232.80	260.87	4.87	SIG
I	9694.21	3	3231.40	43.83	4.04	SIG
NI	5530.51	6	921.75	12.50	3.04	SIG
D	3059.94	1	3059.94	41.50	6.96	SIG
ND	2685.83	2	1342.92	18.21	4.87	SIG
ID	1245.03	3	415.01	5.63	4.04	SIG
NID	1315.46	6	219.24	2.97	3.04	NS
S(NID)	10737.70	24	447.40	6.07	2.03	SIG
Error	7077.66	96	72.73			
TOTAL	79811.93	143				

the denominator of the F test. More detailed descriptions of the techniques employed in the ANOVA can be found in Hicks[26,27].

The sources of variation were tested at the one percent level of significance. The results show a significant operating policies effect, S. The three-way interaction was not found to be significant; however, all of the other main effects and the two way interactions between them were found to be significant. It can be concluded from these results that a substantial reduction in the time spent by pediatric walk-in patients in obtaining medical services can be achieved by adopting the suggested operating policies. It can also be concluded that there are real variations in the response due to each of the two-way interactions and each main effect. The existence of the large interactions indicates that the effect of each of the factors N, I, and D is dependent upon the level of each of the others. In the case of the interactions involving D, these dependencies were induced by the policy changes which were made. Under the rules which were developed for the change in policies, as many as possible (in most cases all) of the scheduled patients being examined on MTTHF under the existing policies were shifted to the Wednesday morning scheduled session. Hence, the number of patients examined on MTTHF was reduced by a factor which was dependent upon the input level and the number of pediatricians in the clinic, while the number of patients examined on Wednesday afternoon was not affected.

Some insight into the main effects and the NI interaction can be gained by an examination of the graphical displays shown in Figures 10 and 11. The three displays in Figure 10 show the response as a function

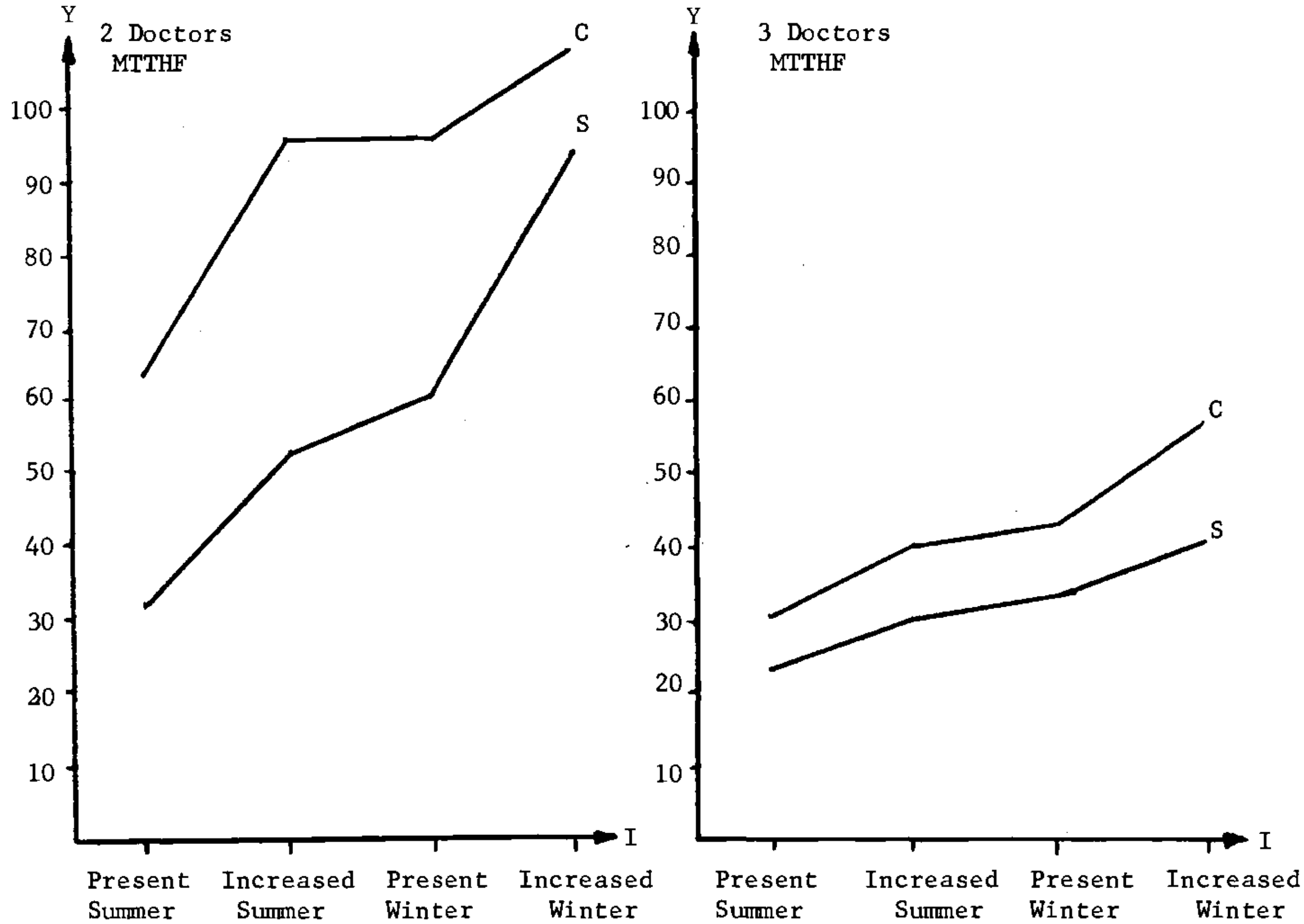


Figure 10. Mean Time Spent by Pediatric Walk-in Patients in Obtaining Medical Services on MTTHF

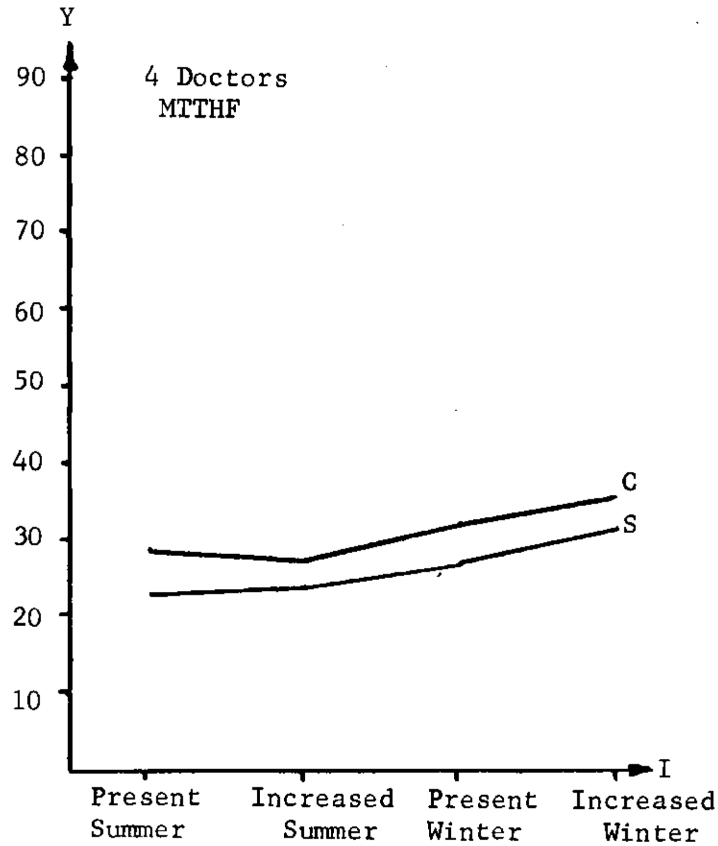


Figure 10. Continued

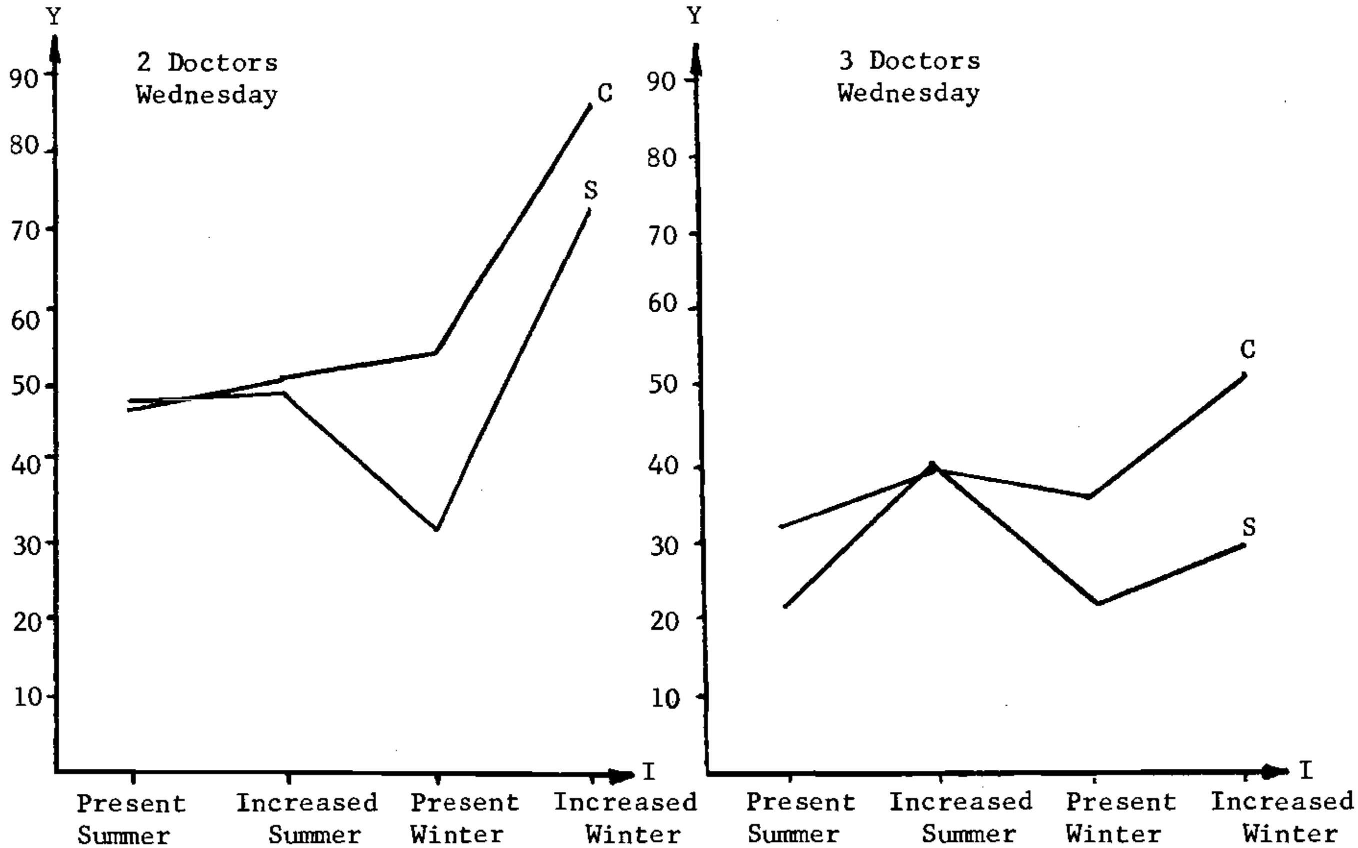


Figure 11. Mean Time Spent by Pediatric Walk-in Patients in Obtaining Medical Services on Wednesday

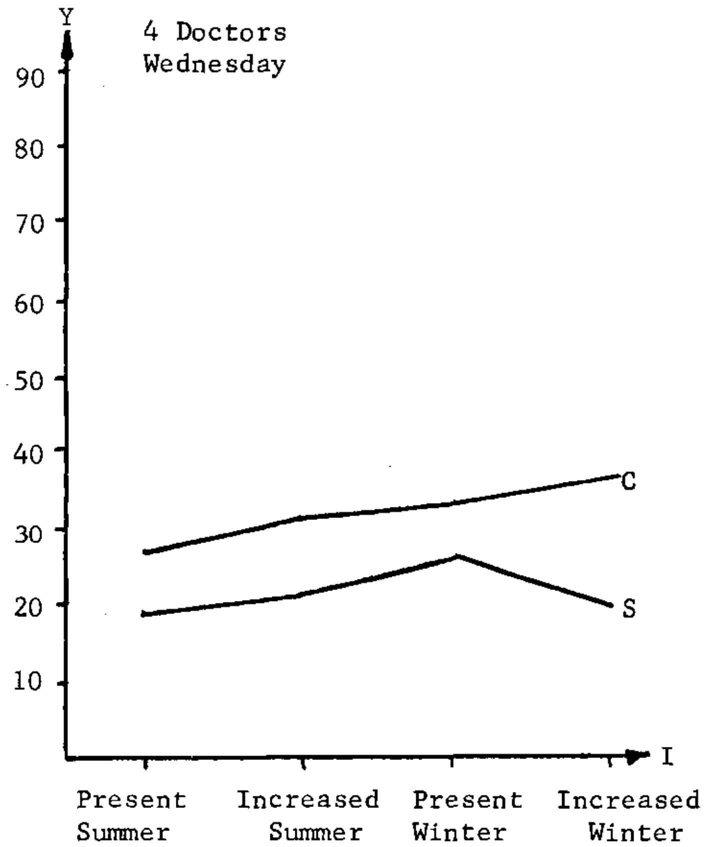


Figure 11. Continued

of the input level with N and D held constant. The curves labeled C represent the responses obtained under current operating policies, and those labeled S indicate the responses for the suggested set of policies. The gaps between the two curves in each set illustrate the sizeable operating policies effect. The gap is largest for a two-pediatrician clinic and decreases as the number of pediatricians increases. This suggests that the benefit which can be achieved by revising the operating policies decreases as the number of available pediatricians increases. The trend in each of the MTTHF curves over the four levels of input indicates the expected input level effect; as the input level increases, the mean time spent in obtaining services rises. The increase in response is largest at the low level of staffing (two pediatricians), smaller at the intermediate staffing level (three pediatricians), and smallest for the high level of staffing (four pediatricians). This suggests an explanation for the NI interaction. The response is quite sensitive to variations in the input level for a two-pediatrician clinic, but it becomes less sensitive as the number of available pediatricians increases.

Examination of the curves for Wednesday walk-in operation (see Figure 11) reveals the same basic patterns noted for MTTHF with the exception that at the low and intermediate levels of staffing there is little difference in the responses for the two sets of operating policies at summer input levels. Recall that under the suggested operating policies as many as possible of the MTTHF scheduled patients were given Wednesday morning appointments. Since no patients were scheduled for Wednesday afternoon under the existing policies, any benefit achieved for these patients as a result of the change in policies was brought about as a result of a more efficient Wednesday morning scheduled operation which permitted the afternoon walk-in patient service to begin earlier. Though the change from a block appointment system to an individualized system resulted in a more efficient and hence shorter Wednesday morning scheduled session, the increase in the number of patients which were scheduled for services during the session tended to offset this advantage, especially during the summer season when routine physical examinations as well as well-baby examinations were scheduled. The overall result was that the duration of the Wednesday morning session was approximately the same for the two sets of policies during the summer season. Thus Wednesday afternoon walk-in service during the summer season was approximately the same under the two sets of policies. Since there was less demand for scheduled services during the winter months, the improvements brought about by the individualized appointment system more than offset the increase in the number of patients scheduled; hence, the Wednesday morning session ended earlier. The result was an improvement in service for Wednesday afternoon walk-in patients during the winter season.

Though this analysis has focused upon the improvement in the primary response, the mean time spent by walk-in patients in obtaining medical services, it is also important to note the accompanying performance of the system in terms of the secondary measures of effectiveness. Table 10 of Appendix III shows the response of the system in terms of the mean time spent in obtaining medical services for scheduled payients. An important aspect of the comparison between the two sets of operating policies was the performance of the system during the Wednesday morning scheduled sessions. A three-way ANOVA was conducted to analyze the effects of N, I, and S upon the time spent by scheduled patients in obtaining medical services during these session. The assumptions and procedure described earlier applied to this analysis. The model was

$$Y_{ijkl} = \mu + N_i + I_j + NI_{ij} + S_{k(ij)} + \epsilon_{l(ijk)}$$

Y_{ijkl} denotes the response

μ, N_i, I_j, and NI_{ij} represent the same factors and levels described for the previous ANOVA

$S_{k(ij)}$ stands for the operating policies where k = 1 and 2

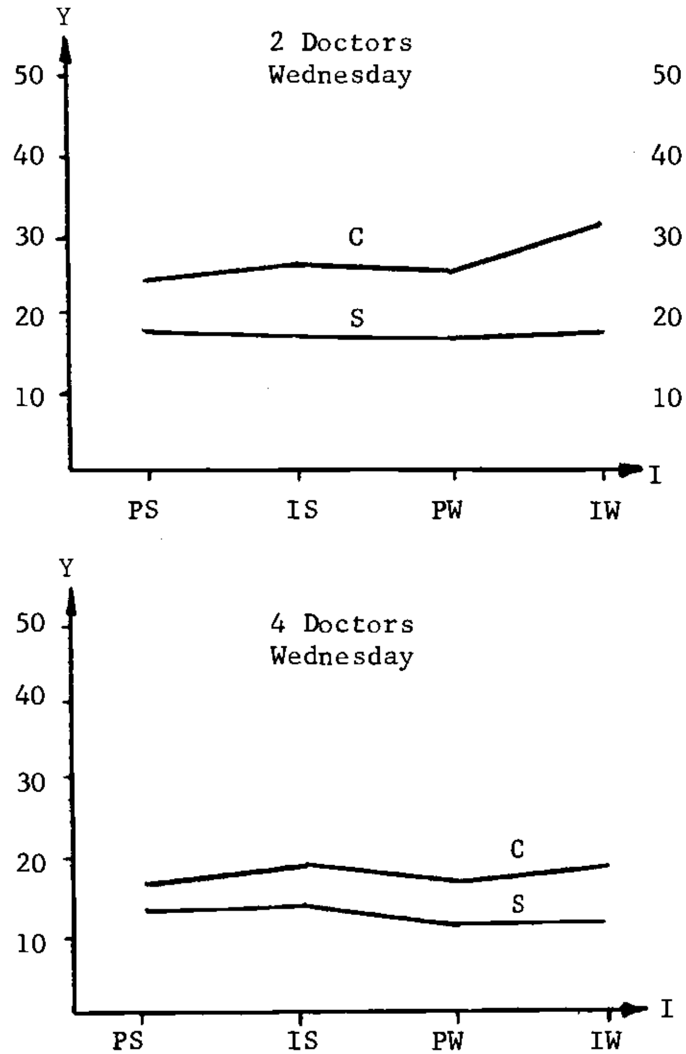
$\epsilon_{l(ijk)}$ represents the random error

The ANOVA is summarized in Table 8. The sources of variation were tested at the one percent level of significance. The results showed a significant operating policies effect, S. The two-way interaction NI was found to be not significant. The main effects N and I were both found to be significant. It can be concluded from these results that the operating policies (in this case the switch to an individualized appointment system) have a very decided effect upon the time spent by scheduled patients in obtaining medical services during the Wednesday morning session. The gaps between the curves in Figure 12 illustrate the sizeable policies effect. It should be recalled that the reduction in response under the suggested set of policies was achieved in spite of a sizeable (25 percent or greater) increase in the number of patients examined during the session.

Responses of the system in terms of the utilization of pediatricians

Table 8. ANOVA for Time Spent in Obtaining Medical Services for Scheduled Patients During Wednesday Morning Sessions

Source	SS	df	MS	F	$F_{\alpha = .01}$	
N	561.44	2	280.72	48.74	5.10	SIG
I	116.31	3	38.77	6.73	4.25	SIG
NI	34.90	6	5.82	1.01	3.22	NS
S(NI)	1082.22	12	90.19	15.66	2.60	SIG
Error	276.56	48	5.76			
TOTAL	2071.43	71				



PS = Present Summer

IS = Increased Summer

PW = Present Winter

IW = Increased Winter

Figure 12. Mean Time Spent by Scheduled Patients in Obtaining Medical Services During Wednesday Morning Session

and the clinic closing time are shown in Tables 11 and 12 respectively of Appendix III. Though these data are presented without analysis for the reasons given in the beginning of this chapter, two points are worthy of note:

1. With respect to the utilization of pediatricians, there appears to be no basis for a choice between the existing and suggested sets of policies. Since the same number of patients is seen on a weekly basis under each set of policies, the total number of pediatrician hours required per week is the same for each.

2. There appears to be no basis for a choice between the two sets of operating policies based upon the clinic closing time data. The only noticeable effect upon this response occurred at the low level of staffing under the two highest levels of input. In each of these cases, the performance of the suggested set of policies is at least equal to that of the existing policies.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

It should be reiterated that this research was concerned with analyzing the operation of a specific outpatient system. Consequently, the results and conclusions contained herein are directly applicable only to that system.

Conclusions

1. The data collection and model building effort described in this study resulted in the development of a model which proved to be adequate for the accomplishment of the research objectives.

2. Estimates of the mean time spent by pediatric patients in obtaining medical services within the system were obtained from the data generated by the model and are presented in Tables 5 and 6.

3. The number of pediatricians available for duty in the system has a significant effect upon the mean time spent in obtaining medical services by walk-in patients. The mean time decreases as the number of pediatricians is increased. This reduction in response is dependent upon the level of input; a larger decrease occurs as the input level increases.

4. The level of input has a significant effect upon the mean time spent by walk-in patients in obtaining medical services within the system. As the input level rises, the mean time increases. The amount of increase in the primary measure of effectiveness varies according to the staffing level; a smaller increase occurs as the number of pediatricians increases.

5. A significant reduction in the mean time spent by walk-in patients in obtaining medical services within the system can be achieved by adopting the modifications to existing patient scheduling policies which are proposed in this study.

6. The mean time spent by scheduled patients in obtaining medical services during the Wednesday morning sessions can be significantly reduced by replacing the existing block appointment system with the proposed system of individual appointments in which the interval between appointments is based upon the mean service time and the number of pediatricians available for duty in the system.

Recommendations

1. The results of this study indicate that the modifications to current operating policies which were developed during the course of this investigation should be implemented in the system. It is believed that the implementation of these changes will result in a significant reduction in the mean time spent in the system by pediatric patients at no cost in terms of the secondary measures of effectiveness.

2. Based upon the results of this study and the experience gained during the course of the investigation, it is recommended that the system continue to operate with three assigned pediatricians. It should be pointed out that at this level of assigned staffing the system would actually operate at the two-pediatrician level for approximately 90 days per year since each assigned pediatrician is authorized 30 days of annual leave. At the current level of input the reduction in the mean time spent in the system by pediatric patients which could be achieved by the addition

of an additional pediatrician does not appear to offset the associated costs.

3. The model which was developed during the course of this study represents a potentially valuable resource which can be used by hospital management to investigate the probable consequences of modifications which may be proposed in the future or the impact of anticipated changes in system parameters. The model is sufficiently flexible to permit the investigation of a variety of situations and proposed system configurations with only minor modifications.

Recommendations for Further Study

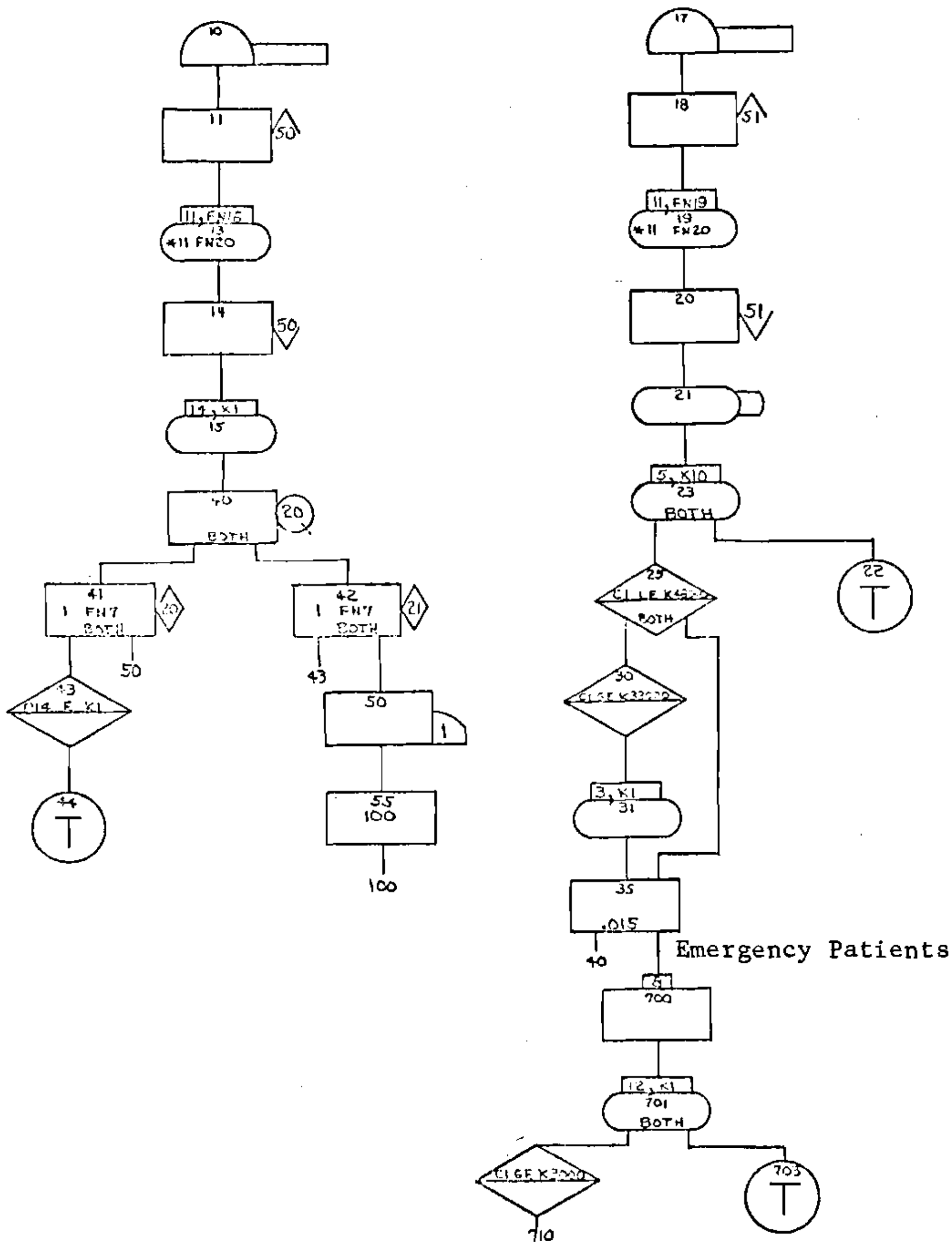
1. The model which was developed during the course of this study could be used as the initial building block in the construction of a complete hospital model. The method of attack and techniques of data collection and model building presented herein are readily adaptable to such an undertaking. The benefits and costs which would be associated with the construction of such a model merit careful consideration.

2. The investigation of methods which might be used to modify the characteristics of walk-in patient input would be a valuable addition to this research. It is this author's opinion that a substantial improvement could be achieved in each measure of effectiveness if methods could be developed which would have the effect of leveling the patient arrival rate.

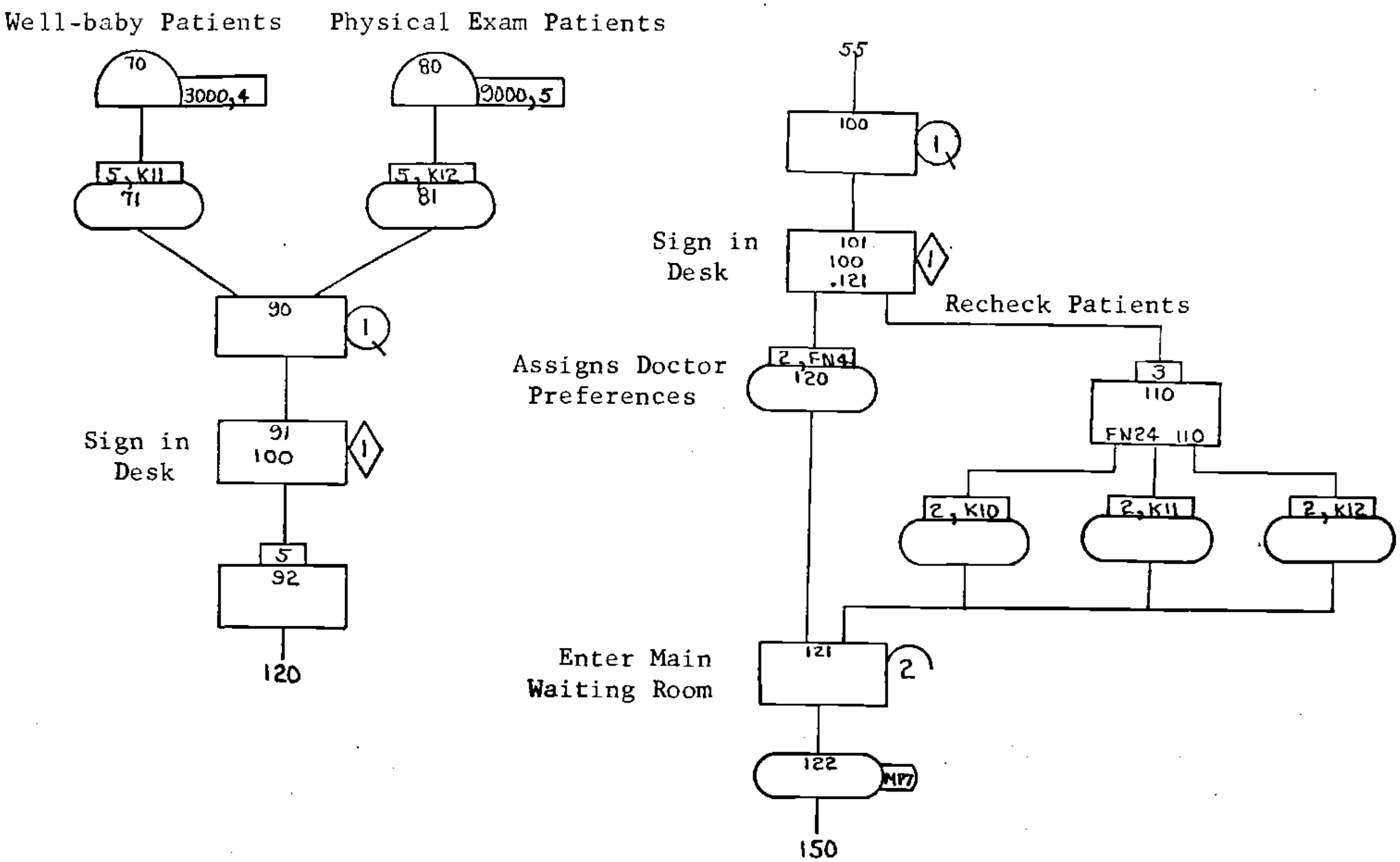
APPENDIX I

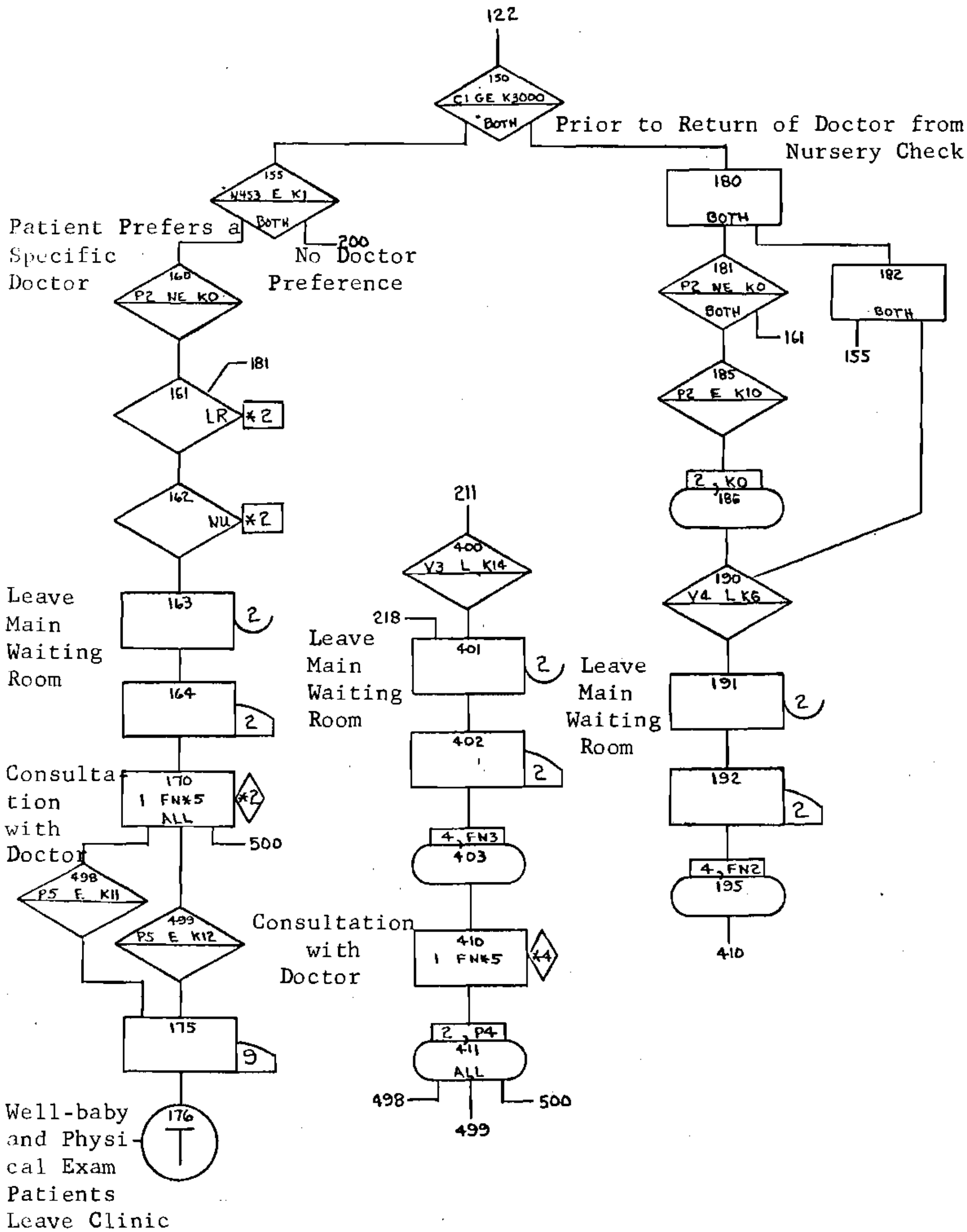
GPSS BLOCK DIAGRAM

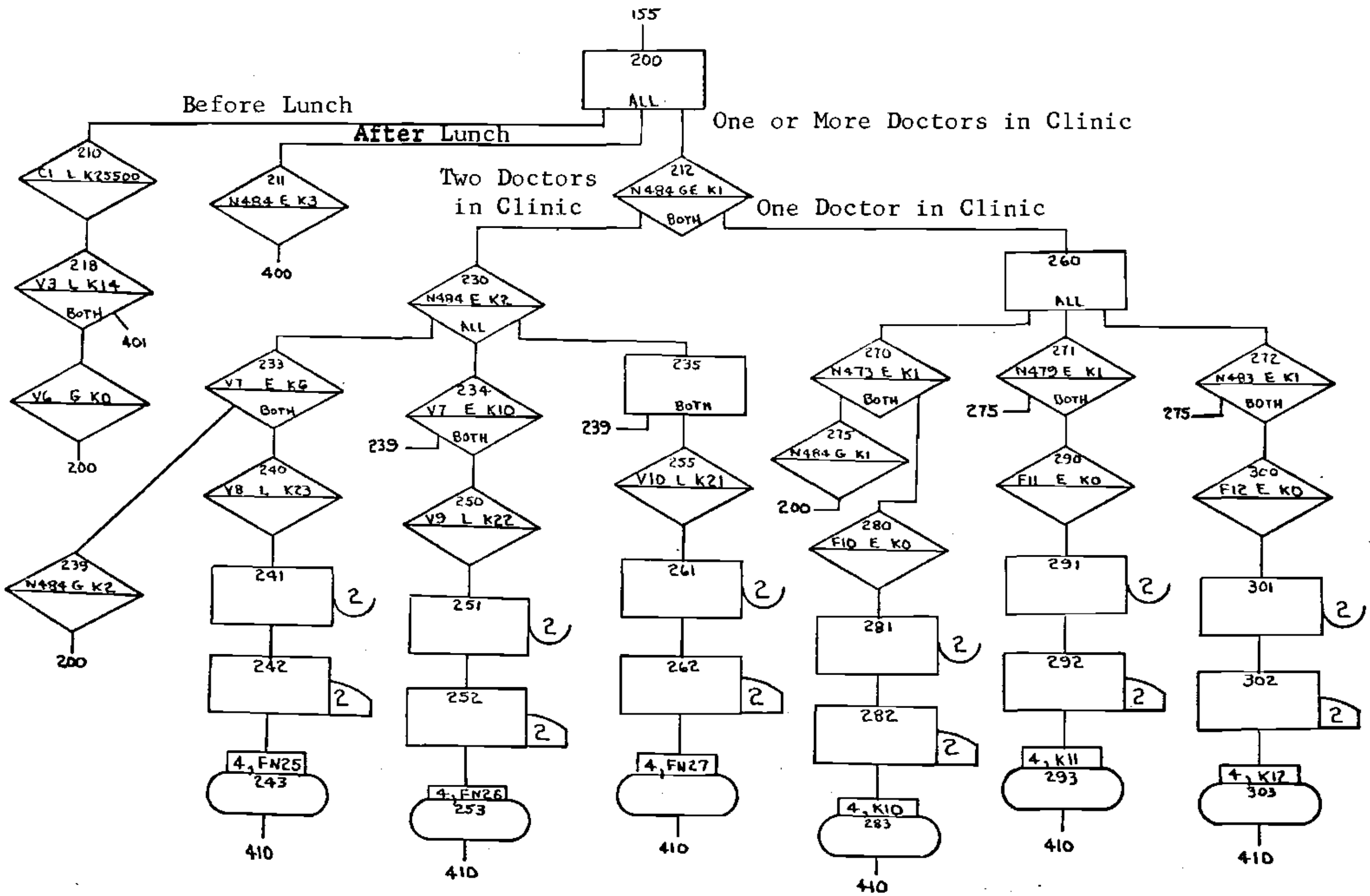
Non-pediatric Patients　　　Pediatric Walk-in Patients

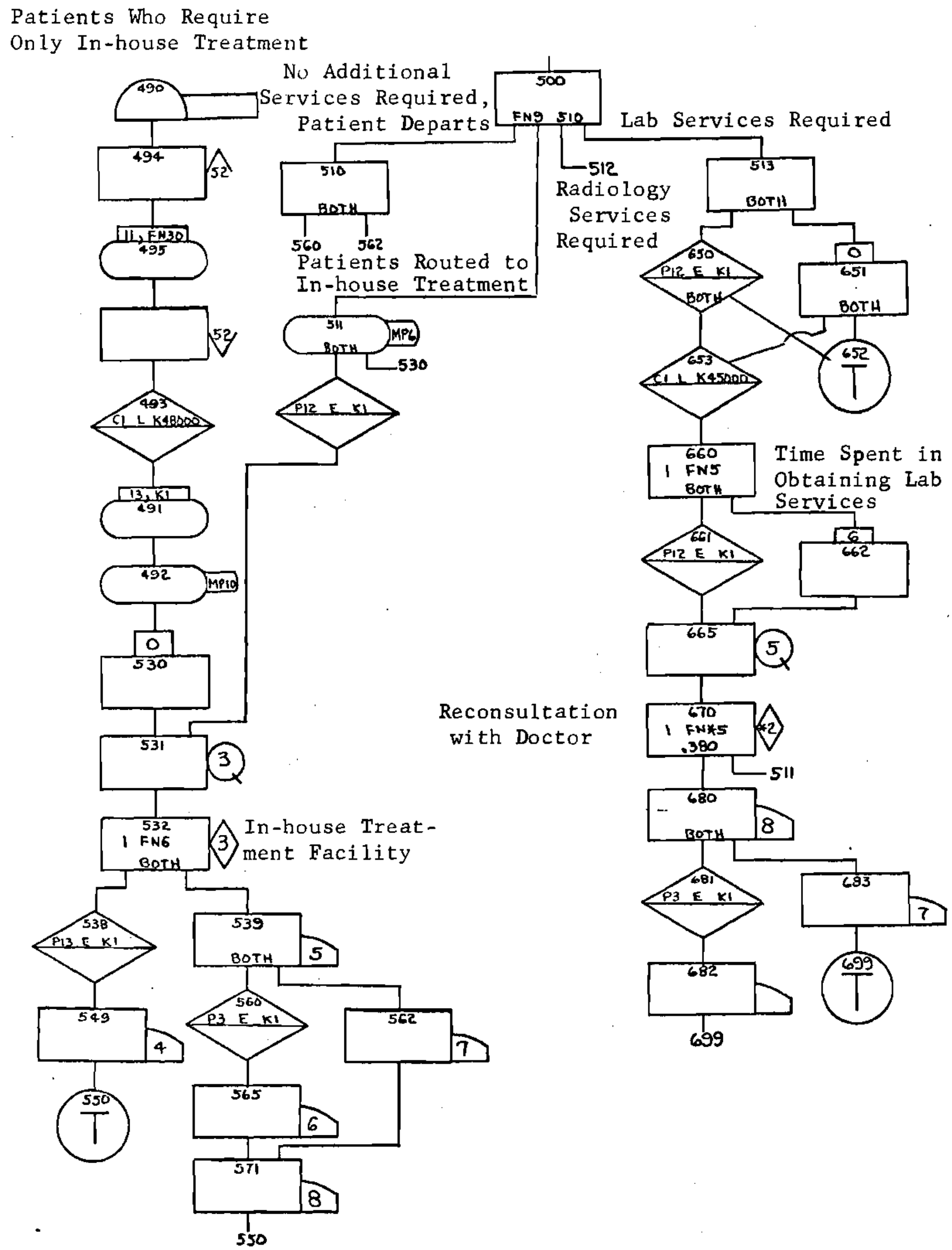


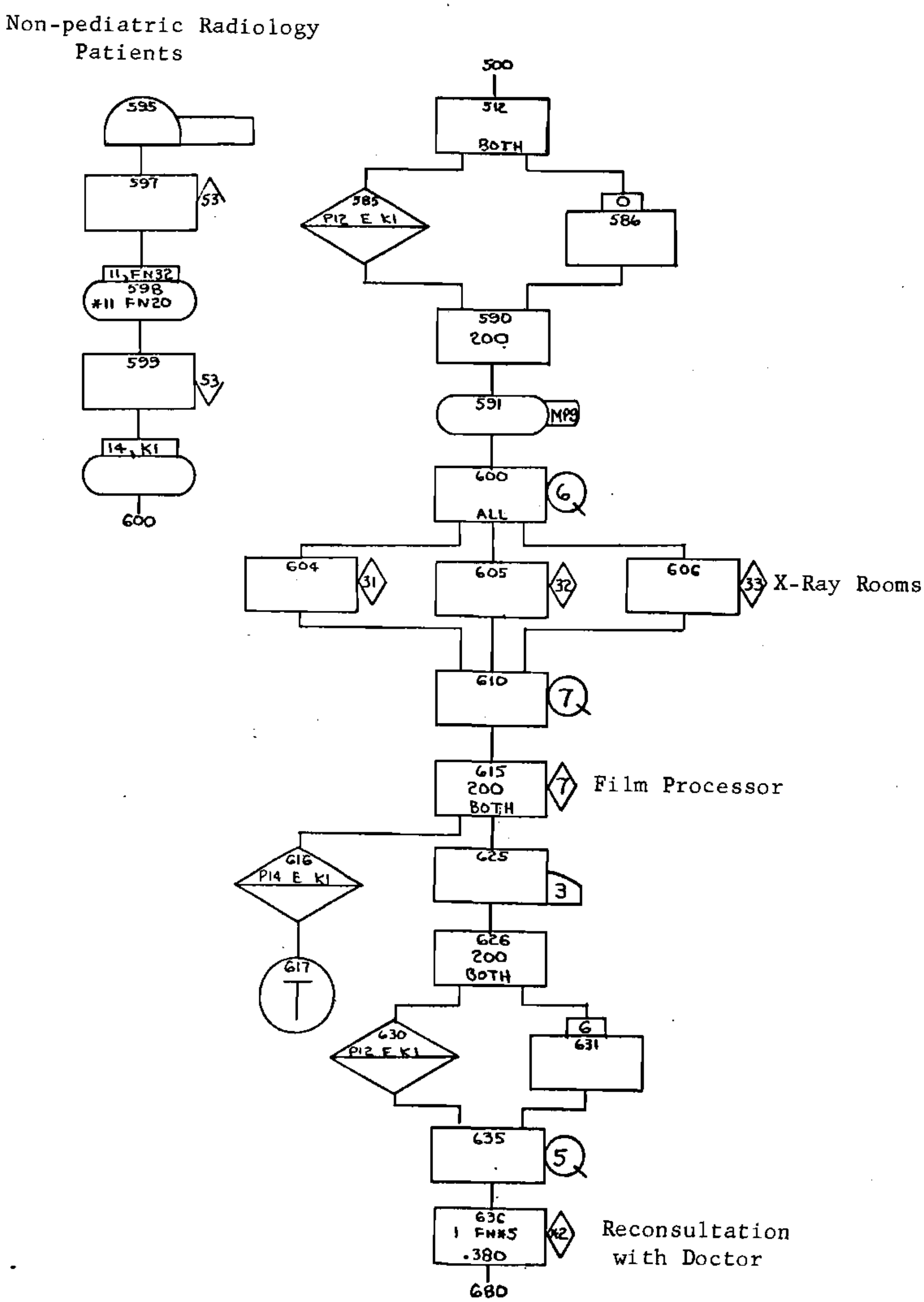
Emergency Patients

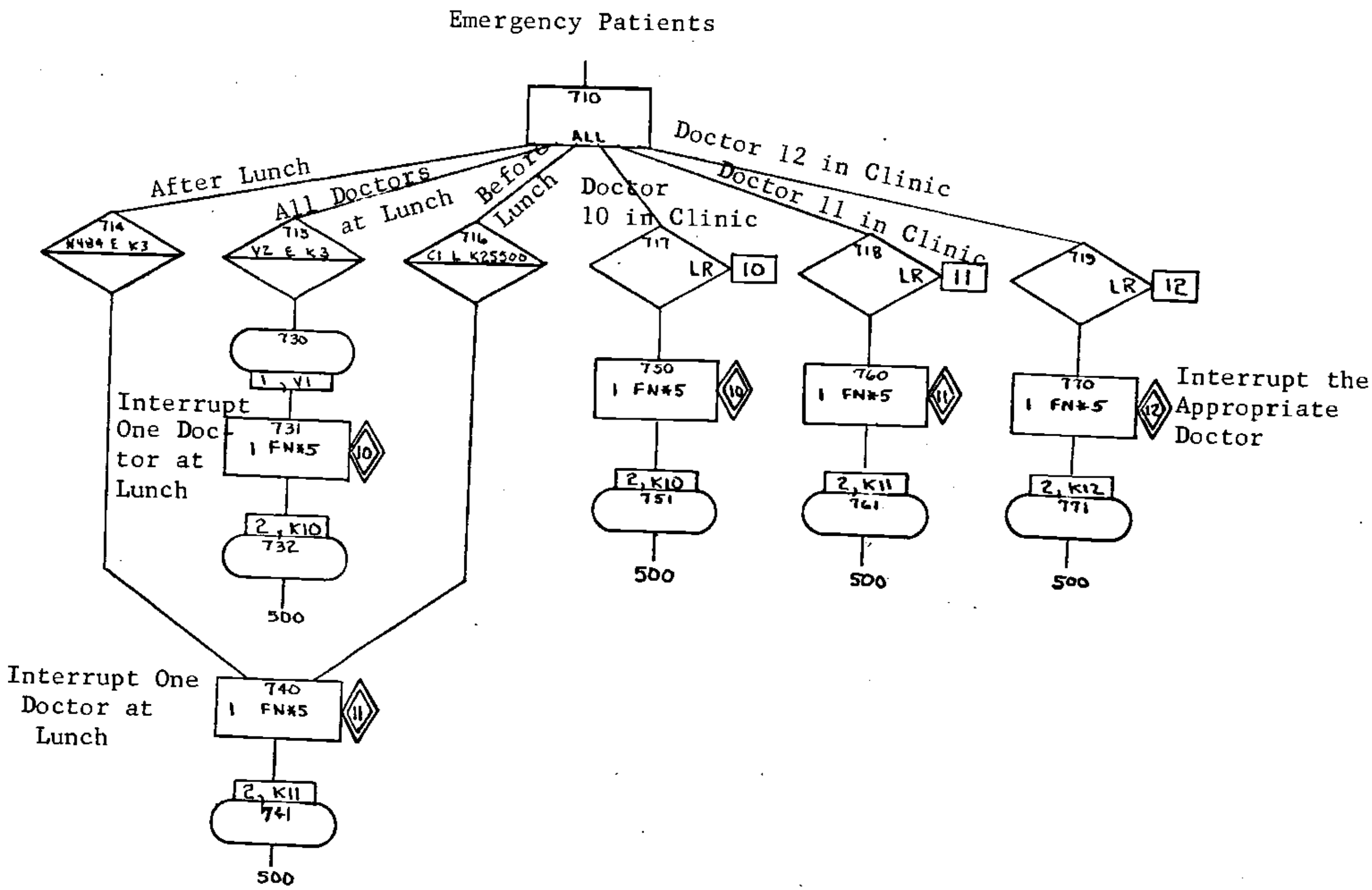

Well-baby Patients
Physical Exam Patients
70
3000,4
80
9000,5
5,K11
71
5,K12
81
90
1
Sign in
Desk
91
100
1
5
92
120
55
100
1
Sign in
Desk
101
100
.121
1
Recheck Patients
Assigns Doctor
Preferences
2,FN4
120
3
110
FN24 110
2,K10
2,K11
2,K12
Enter Main
Waiting Room
121
2
122
MP7
150

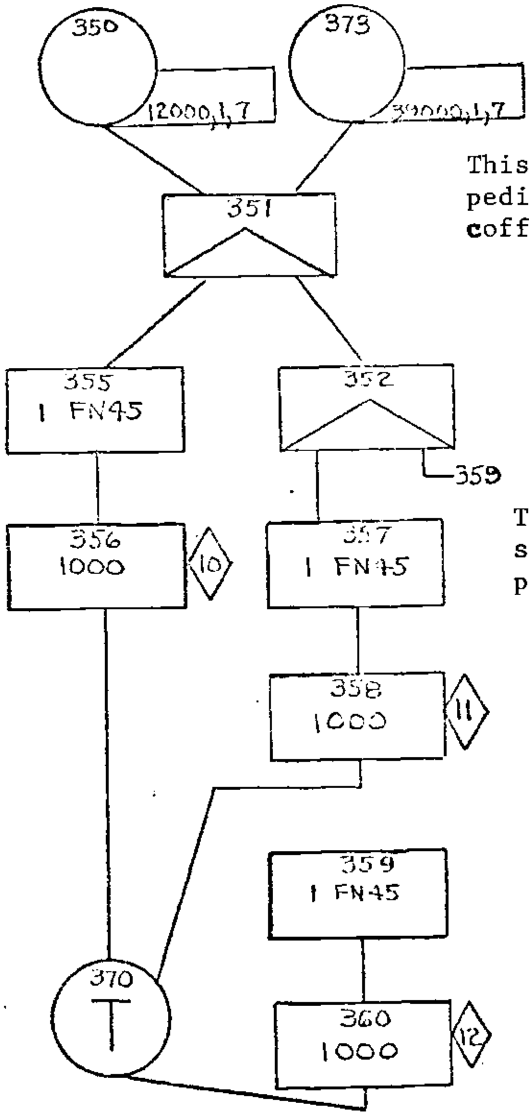

122
150
C1 GE K3000
BOTH
Prior to Return of Doctor from Nursery Check
155
N453 E K1
BOTH
Patient Prefers a Specific Doctor
200
No Doctor Preference
160
P2 NE K0
181
161
LR
*2
162
NU
*2
Leave Main Waiting Room
163
2
164
2
Consultation with Doctor
170
1 FN*5
ALL
*2
500
498
P5 E K11
499
P5 E K12
175
9
Well-baby and Physical Exam Patients Leave Clinic
176
T
211
400
V3 L K14
218
Leave Main Waiting Room
401
2
402
2
4, FN3
403
Consultation with Doctor
410
1 FN*5
*4
2, P4
411
ALL
498
499
500
180
BOTH
181
P2 NE K0
BOTH
161
182
BOTH
155
185
P2 E K10
2, K0
186
190
V4 L K6
Leave Main Waiting Room
191
2
192
2
4, FN2
195
410


155
200
ALL
Before Lunch
After Lunch
One or More Doctors in Clinic
210
C1 L K25500
211
N484 E K3
400
212
N484 GE K1
BOTH
Two Doctors in Clinic
One Doctor in Clinic
218
V3 L K14
BOTH
401
V6 G K0
200
230
N484 E K2
ALL
260
ALL
233
V7 E K6
BOTH
234
V7 E K10
BOTH
239
235
BOTH
239
270
N473 E K1
BOTH
271
N479 E K1
BOTH
275
272
N483 E K1
BOTH
275
275
N484 G K1
200
240
V8 L K23
250
V9 L K22
255
V10 L K21
280
F10 E K0
290
F11 E K0
300
F12 E K0
239
N484 G K2
200
241
2
251
2
261
2
281
2
291
2
301
2
242
2
252
2
262
2
282
2
292
2
302
2
4, FN25
243
4, FN26
253
4, FN27
4, K10
283
4, K11
293
4, K12
303
410
410
410
410
410
410


Patients Who Require
Only In-house Treatment
No Additional
Services Required,
Patient Departs
Lab Services Required
512
Radiology
Services
Required
Patients Routed to
In-house Treatment
Time Spent in
Obtaining Lab
Services
Reconsultation
with Doctor
In-house Treat-
ment Facility

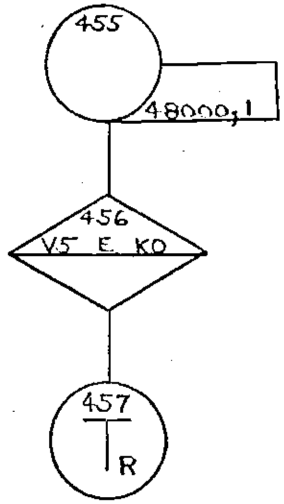

Non-pediatric Radiology
Patients
500
512
BOTH
585
P12 E K1
586
595
597
53
11, FN32
598
#11 FN20
599
53
14, K1
600
590
200
591
MPS
600
ALL
6
604
31
605
32
606
33
X-Ray Rooms
610
7
615
200
BOTH
7
Film Processor
616
P14 E K1
617
T
625
3
626
200
BOTH
630
P12 E K1
631
6
635
5
636
1 FN*5
.380
42
Reconsultation
with Doctor
680

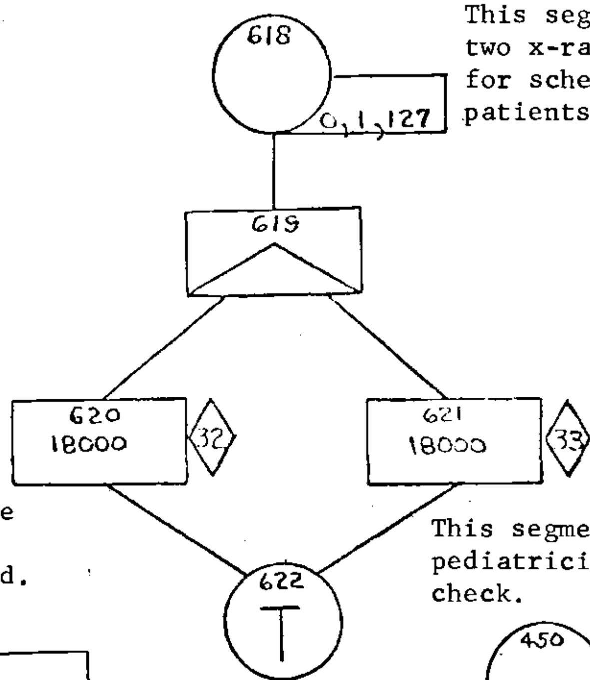

Emergency Patients
710
ALL
After Lunch
All Doctors at Lunch
Before Lunch
Doctor 10 in Clinic
Doctor 11 in Clinic
Doctor 12 in Clinic
714
N484 E K3
715
V2 E K3
716
C1 L K25500
717
LR
10
718
LR
11
719
LR
12
730
1, V1
Interrupt One Doctor at Lunch
731
1 FN*5
10
2, K10
732
500
750
1 FN*5
10
2, K10
751
500
760
1 FN*5
11
2, K11
761
500
770
1 FN*5
12
Interrupt the Appropriate Doctor
2, K12
771
500
Interrupt One Doctor at Lunch
740
1 FN*5
11
2, K11
741
500



This segment sends each pediatrician on two coffee breaks.

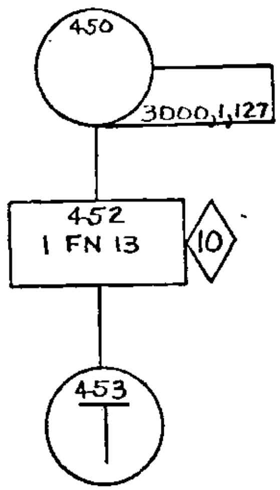
This segment stops the simulation when all patients have departed.



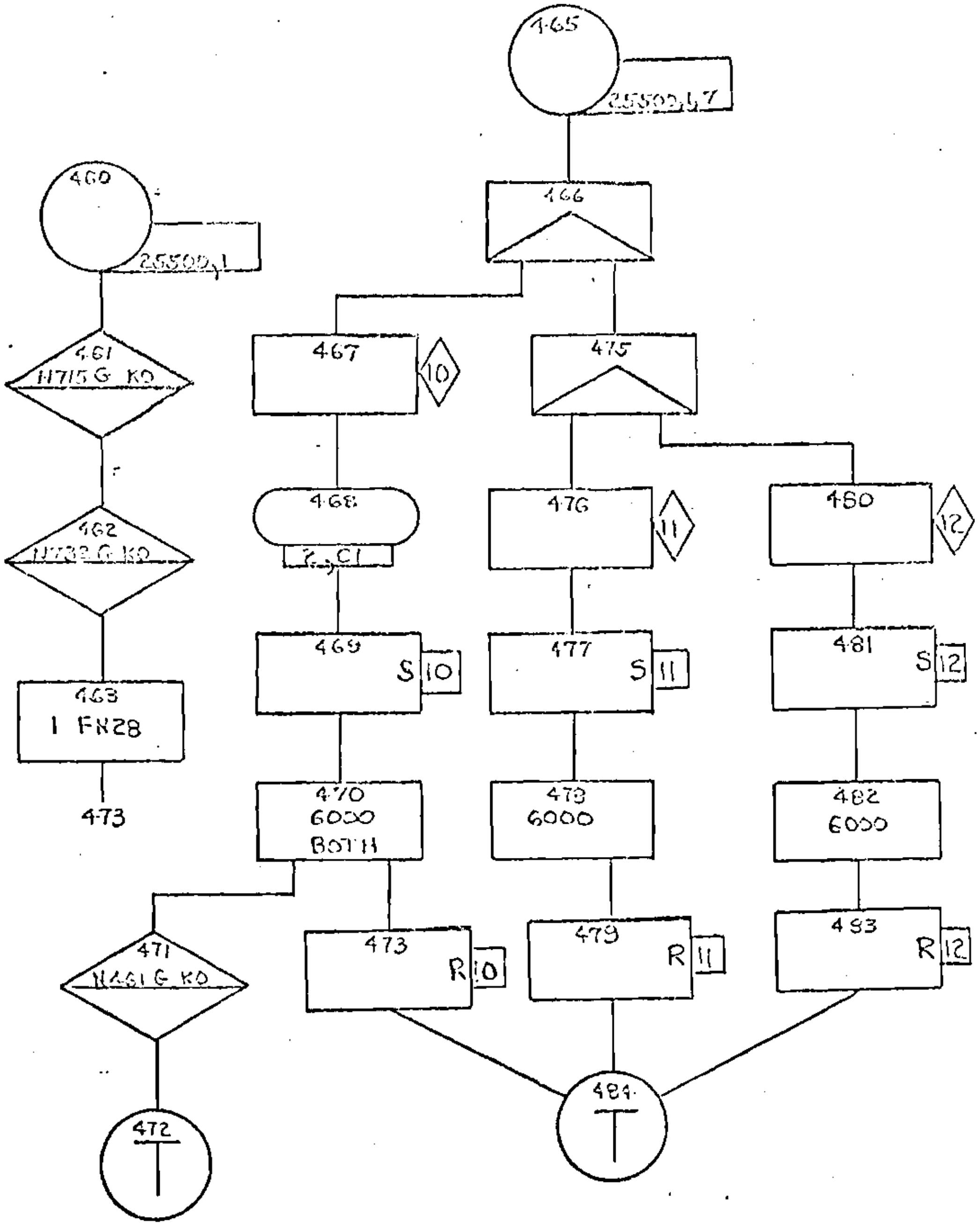


This segment holds two x-ray rooms for scheduled patients.

This segment sends one pediatrician on nursery check.



This segment sends the pediatricians to lunch.



APPENDIX II

PROGRAM COMPILATION

```
        JOB          102561702575
*       BASIC MODEL OF PEDIATRIC CLINIC, FORT MCPHERSON, GEORGIA
  2     CAPACITY     1001
  1     VARIABLE     F600J0+X2-C1
  2     VARIABLE     W47?+W47?+W482
  3     VARIABLE     K6*F10+K4*F11+K2*F12
  4     VARIABLE     F4*F11+K2*F12
  5     VARIABLE     F1+F1+S2+Q3+F3+F10+F11+F12+Q5
  6     VARIABLE     W467+W47?+W4?0
  7     VARIABLE     W47?*K6+W479*K4+W483*K2
  8     VARIABLE     F11+K11+F12*K12
  9     VARIABLE     F10+K10+F12*K12
 10     VARIABLE     F10*K10+F11*K11
 13     VARIABLE     FN1*K21078/K10000/K100+K5076
 14     VARIABLE     FN1*K28490/K10000/K100+K7224
 25     VARIABLE     FN1*K13550/K10000/K1000+K904
 26     VARIABLE     FN1*K22210/K10000/K1000+K1191
  1     FUNCTION     FN1    C25
0       -50000,00003-40000,00135-30000,00621-25000,02275-20000,06681-15000
.11507-12000,15866-10000,21186-8000 ,27425-6000 ,34458-4000 ,42074-2000
.5      0      .5792600   .6554240000 .7257560000 .7881460000 .8413410000
.8849312000 .93319150 0 .9772520000 .9937925000 .9986530000 .9999740000
1.0     50000
  2     FUNCTION     V4     D2
2       11     4      12
  3     FUNCTION     V3     D3
7       10     11     11     13     12
  4     FUNCTION     FN1    D4
.03     10     .07    11     .1     12     1      0
  5     FUNCTION     V14    C2
0       0      999999999999
  6     FUNCTION     FN1    C27
0       0      .001   50     .009   100    .033   150    .078   200    .141   250
.218    300    .305   350    .394   400    .481   450    .563   500    .637   550
.702    600    .759   650    .806   700    .846   750    .879   800    .905   850
.926    900    .956   1000   .975   1100   .986   1200   .992   1300   .996   1400
.998    1500   .999   1600   .9998  1900
  7     FUNCTION     FN1    C27
0       0      .047   10     .134   25     .215   50     .305   75     .384   100
.455    125    .517   150    .572   175    .621   200    .664   225    .703   250
.767    300    .817   350    .856   400    .887   450    .912   500    .946   600
.966    700    .979   800    .987   900    .992   1000   .995   1100   .997   1200
.998    1300   .999   1400   .9998  1800
  8     FUNCTION     FN1    C31
0       0      .001   50     .018   100    .029   150    .068   200    .125   250
.197    300    .277   350    .319   375    .362   400    .404   425    .446   450
.527    500    .601   550    .668   600    .726   650    .777   700    .820   750
.8560800       .885   850    .910   900    .926   950    .945   1000   .967   1100
.981    1200   .989   1300   .994   1400   .996   1500   .998   1600   .999   1700
.9999   2100
  9     FUNCTION     FN1    D4
.521    0      .901   1      .929   2      1      3
 10     FUNCTION     FN1    C35
```

```
0      0      .007   50     .026   100    .055   150    .089   200    .129   250
.172   300    .217   350    .263   400    .308   450    .353   500    .397   550
.440   600    .520   700    .592   800    .655   900    .710   1000   .758   1100
.799   1200   .833   1300   .862   1400   .887   1500   .907   1600   .924   1700
.938   1800   .950   1900   .959   2000   .967   2100   .973   2200   .978   2300
.982   2400   .986   2500   .988   2600   .995   3200   .9999  4200
 11    FUNCTION      V25    C2
0      0      999999999999
 12    FUNCTION      V26    C2
0      0      999999999999
 13    FUNCTION      V13    C2
0      0      999999999999
 16    FUNCTION      C1     C4
0      109    27000  667    33000  391    48000  935
 19    FUNCTION      C1     C5
0      781    10500  433    27000  1190   34500  694    48000  1449
 20    FUNCTION      RN1    C24
0      0      .1     0.1040.200000.2220.300000.3550.400000.5090.500000.6900
.600000.9150.700001.2000.750001.3800.800001.6000.840001.8300.880002.1200
.900002.3000.920002.5200.940002.8100.950002.9900.960003.2000.970003.5000
.980003.9000.990004.6000.995005.3000.998006.2000.999007.0000.999708.0000
 24    FUNCTION      RN1    D3
.333   1      .666   2      1      3
 25    FUNCTION      V8     D2
11     11     12     12
 26    FUNCTION      V9     D2
10     10     12     12
 27    FUNCTION      V10    D2
10     10     11     11
 28    FUNCTION      X1     C2
0      0      999999999999
 30    FUNCTION      C1     C4
0      20000  33000  20000  36000  1176   48000  14286
 32    FUNCTION      C1     C3
0      820    27000  820    48000  5263
 45    FUNCTION      RN1    C2
0      0      1      6000
*      NURSERY CHECK
  450  ORIGINATE     30     1      127                  452           1
  452  HOLD          10                                 453           1      FN13
  453  TERMINATE
  455  ORIGINATE     48000  1                           456           1
  456  COMPARE       V5     E      K0                   457
  457  TERMINATE     R
  460  ORIGINATE     25500  1                           461           1
  461  COMPARE       M715   G      K0                   462
  462  COMPARE       M732   G      K0                   463
  463  ADVANCE                                          473           1      FN28
  465  ORIGINATE     25500  1      7                    466           1
  466  SPLIT                                            467    475
  467  HOLD          10                                 468
  468  SAVEX         2      C1                          469
  469  LOGIC         S10                                470
  470  ADVANCE                            BOTH          471    473    6000
  471  COMPARE       M461   G      K0                   472
  472  TERMINATE
  473  LOGIC         R10                                484
```

475	SPLIT					476	480		
476	HOLD	11				477			
477	LOGIC	S11				478			
478	ADVANCE					479		6000	
479	LOGIC	R11				484			
480	HOLD	12				481			
481	LOGIC	S12				482			
482	ADVANCE					483		6000	
483	LOGIC	R12				484			
484	TERMINATE								
350	GENERATE	12000	1	7		351			
351	SPLIT					355	352		
355	ADVANCE					356		1	FN45
356	HOLD	10				370		1000	
352	SPLIT					357	359		
357	ADVANCE					358		1	FN45
358	HOLD	11				370		1000	
359	ADVANCE					360		1	FN45
360	HOLD	12				370		1000	
370	TERMINATE								
618	ORIGINATE	0	1	127		619		1	
619	SPLIT					620	621		
620	HOLD	32				622		18000	
621	HOLD	33				622		18000	
622	TERMINATE								
*	MAIN PROGRAM								
10	GENERATE					11			
11	SEIZE	50				12			
12	ASSIGN	11	FN16			13		*11	FN20
13	RELEASE	50				15			
15	ASSIGN	14	K1			40			
17	GENERATE					18			
18	SEIZE	51				19			
19	ASSIGN	11	FN19			20		*11	FN20
20	RELEASE	51				21			
21	MARK					23			
23	ASSIGN	5	K10		BOTH	25	22		
22	TERMINATE								
25	COMPARE	C1	LE	K48000	BOTH	30	35		
30	COMPARE	C1	GE	K33000		31			
31	ASSIGN	3	K1			35			
35	ADVANCE				.015	40	700		
40	QUEUE	20			BOTH	41	42		
10	QTABLE	20	0	100	20				
41	HOLD	20			BOTH	43	50	1	FN7
42	HOLD	21			BOTH	43	50	1	FN7
43	COMPARE	P14	E	K1		44			
44	TERMINATE								
50	TABULATE	1				55			
1	TABLE	M1	100	100	20				
55	ADVANCE					100		100	
70	GENERATE	3000	4			71			
71	ASSIGN	5	K11			90			
80	GENERATE	9000	5			81			
81	ASSIGN	5	K12			90			
90	QUEUE	1				91			
11	QTABLE	1	0	100	20				

91	HOLD	1				92		100	
92	PRIORITY	5				120			
100	QUEUE	1				101			
101	HOLD	1			.121	120	110	100	
110	PRIORITY	3			FN	24	110		
111	ASSIGN	2	K10			121			
112	ASSIGN	2	K11			121			
113	ASSIGN	2	K12			121			
120	ASSIGN	2	FN4			121			
121	ENTER	2				122			
122	MARK	FP7				150			
150	COMPARE	C1	GE	K3000	BOTH	155	180		
155	COMPARE	M453	E	K1	BOTH	160	200		
160	COMPARE	P2	NE	K0		161			
161	GATE	LR*2				162			
162	GATE	LU*2				163			
163	LEAVE	2				164			
164	TABULATE	2				170			
2	TABLE	FP7	0	500	21				
170	HOLD	*2			ALL	498	500	1	FN*5
498	COMPARE	P5	E	K11		175			
499	COMPARE	P5	E	K12		175			
175	TABULATE	9				176			
9	TABLE	M1	500	500	20				
176	TERMINATE								
180	ADVANCE				BOTH	181	182		
182	ADVANCE				BOTH	155	190		
181	COMPARE	P2	NE	K0	BOTH	185	161		
185	COMPARE	P2	E	K10		186			
186	ASSIGN	2	K0			190			
190	COMPARE	V4	L	K6		191			
191	LEAVE	2				192			
192	TABULATE	2				195			
195	ASSIGN	4	FN2			410			
200	ADVANCE				ALL	210	212		
210	COMPARE	C1	L	K25500		218			
211	COMPARE	M484	E	K3		400			
212	COMPARE	M484	GE	K1	BOTH	230	260		
218	COMPARE	V3	L	K14	BOTH	219	401		
219	COMPARE	V6	G	K0		200			
230	COMPARE	M484	E	K2	ALL	233	235		
233	COMPARE	V7	E	K6	BOTH	239	240		
239	COMPARE	M484	G	K2		200			
240	COMPARE	V8	L	K23		241			
241	LEAVE	2				242			
242	TABULATE	2				243			
243	ASSIGN	4	FN25			410			
234	COMPARE	V7	E	K10	BOTH	239	250		
250	COMPARE	V9	L	K22		251			
251	LEAVE	2				252			
252	TABULATE	2				253			
253	ASSIGN	4	FN26			410			
235	ADVANCE				BOTH	239	255		
255	COMPARE	V10	L	K21		261			
261	LEAVE	2				262			
262	TABULATE	2				263			
263	ASSIGN	4	FN27			410			

260	ADVANCE				ALL	270	272		
270	COMPARE	M473	E	K1	BOTH	275	280		
275	COMPARE	M484	G	K1		200			
280	COMPARE	F10	E	K0		281			
281	LEAVE	2				282			
282	TABULATE	2				283			
283	ASSIGN	4	K10			410			
271	COMPARE	M479	E	K1	BOTH	275	290		
290	COMPARE	F11	E	K0		291			
291	LEAVE	2				292			
292	TABULATE	2				293			
293	ASSIGN	4	K11			410			
272	COMPARE	M483	E	K1	BOTH	275	300		
300	COMPARE	F12	E	K0		301			
301	LEAVE	2				302			
302	TABULATE	2				303			
303	ASSIGN	4	K12			410			
400	COMPARE	V3	L	K14		401			
401	LEAVE	2				402			
402	TABULATE	2				403			
403	ASSIGN	4	FN3			410			
410	HOLD	*4				411		1	FN*5
411	ASSIGN	2	P4		ALL	498	500		
500	ADVANCE				FN	9	510		
510	ADVANCE				BOTH	560	562		
490	GENERATE					494			
494	SEIZE	52				495			
495	ASSIGN	11	FN30			496		*11	FN20
496	RELEASE	52				493			
493	COMPARE	C1	L	K48000		491			
491	ASSIGN	13	K1			492			
492	MARK	MP10				530			
511	MARK	MP6			BOTH	529	530		
529	COMPARE	P12	E	K1		531			
530	PRIORITY	0				531			
531	QUEUE	3				532			
12	QTABLE	3	0	100	21				
532	HOLD	3			BOTH	538	539	1	FN6
538	COMPARE	P13	E	K1		549			
549	TABULATE	4				550			
4	TABLE	MP10	500	500	5				
550	TERMINATE								
539	TABULATE	5			BOTH	560	562		
5	TABLE	MP6	100	500	5				
560	COMPARE	P3	L	K1		565			
565	TABULATE	6				571			
6	TABLE	M1	500	500	50				
562	TABULATE	7				571			
7	TABLE	M1	500	500	50				
3	TABLE	MP9	500	500	20				
571	TABULATE	8				550			
8	TABLE	M1	500	500	50				
512	ADVANCE				BOTH	585	586		
585	COMPARE	P12	E	K1		590			
586	PRIORITY	0				590			
590	ADVANCE					591		200	50
591	MARK	MP9				600			

595	GENERATE					597			
597	SEIZE	53				598			
598	ASSIGN	11	FN32			599		*11	FN20
599	RELEASE	53				596			
596	ASSIGN	14	K1			600			
600	QUEUE	6			ALL	604	606		
14	QTABLE	6	0	-500	5				
604	HOLD	31				610		1	FN8
605	HOLD	32				610		1	FN8
606	HOLD	33				610		1	FN8
610	QUEUE	7				615			
13	QTABLE	7	0	100	11				
615	HOLD	7			BOTH	616	625	200	
616	COMPARE	P14	E	K1		617			
617	TERMINATE								
625	TABULATE	3				626			
626	ADVANCE				BOTH	630	631	200	50
630	COMPARE	P12	E	K1		635			
631	PRIORITY	6				635			
635	QUEUE	5				636			
636	HOLD	*2			.380	640	511	1	FN*5
640	TABULATE	8			BOTH	641	643		
641	COMPARE	P3	E	K1		642			
643	TABULATE	7				649			
642	TABULATE	6				649			
649	TERMINATE								
513	ADVANCE				BOTH	650	651		
650	COMPARE	P12	E	K1	BOTH	653	652		
651	PRIORITY	0			BOTH	653	652		
652	TERMINATE								
653	COMPARE	C1	L	K45000		660			
660	ADVANCE				BOTH	661	662	1	FN5
661	COMPARE	P12	E	K1		665			
662	PRIORITY	6				665			
665	QUEUE	5				670			
14	QTABLE	5	0	500	5				
670	HOLD	*2			.380	680	511	1	FN*5
680	TABULATE	8			BOTH	681	683		
681	COMPARE	P3	E	K1		682			
682	TABULATE	6				699			
683	TABULATE	7				699			
699	TERMINATE								
700	PRIORITY	8				701			
701	ASSIGN	12	K1		BOTH	702	703		
702	COMPARE	C1	GE	K3000		710			
703	TERMINATE								
710	ADVANCE				ALL	714	719		
714	COMPARE	N484	E	K3		740			
740	INTERRUPT	11				741		1	FN*5
741	ASSIGN	2	K11			500			
715	COMPARE	V2	E	K3		730			
730	SAVEX	1	V1			731			
731	INTERRUPT	10				732		1	FN*5
732	ASSIGN	2	K10			500			
716	COMPARE	C1	L	K25500		740			
717	GATE	LR10				750			
750	INTERRUPT	10				751		1	FN*5

751	ASSIGN	2	K1	500		
718	GATE	LR11		760		
760	INTERRUPT	11		761	1	FN*5
761	ASSIGN	2	K11	500		
719	GATE	LR12		770		
770	INTERRUPT	12		771	1	FN*5
771	ASSIGN	2	K12	500		
	START	1				

APPENDIX III

EXPERIMENTAL RESULTS FOR MEASURES OF EFFECTIVENESS

Table 9. Mean Time Spent in Obtaining Medical Services for Pediatric Walk-in Patients

	Present Summer Input Level		Present Winter Input Level		25% Increase to Summer Input		25% Increase to Winter Input		
	M	W	M	W	M	W	M	W	
	80.78	59.88	110.23	62.55	105.62	56.70	124.29	87.73	Current Policies
2 Doctors	55.09	48.05	94.06	54.49	74.10	53.85	130.14	79.71	
	56.53	33.05	90.87	46.28	106.66	46.75	96.75	88.85	
	30.74	34.26	52.76	33.71	43.54	32.98	58.73	59.13	
3 Doctors	30.89	31.59	39.90	39.44	42.50	44.87	68.06	43.93	
	30.70	30.87	37.43	31.89	35.03	40.28	46.23	48.71	
	22.69	30.72	31.79	36.73	25.22	29.39	39.42	36.83	
4 Doctors	35.25	21.27	30.98	36.31	28.22	34.67	30.38	25.90	
	27.11	26.37	33.36	25.78	26.12	33.62	37.73	44.94	
	31.24	37.57	64.70	27.63	48.66	48.83	116.27	81.52	Suggested Policies
2 Doctors	26.35	56.66	64.85	30.96	44.19	46.33	103.72	62.72	
	38.29	48.87	50.67	31.67	65.88	53.91	63.37	75.66	
	17.51	22.97	44.79	22.39	28.22	34.68	43.87	33.78	
3 Doctors	32.36	26.04	27.70	24.32	38.26	42.28	38.41	27.61	
	22.54	17.87	30.74	18.50	23.96	43.31	42.74	23.44	
	20.67	21.77	23.06	26.70	27.32	22.31	38.34	25.00	
4 Doctors	24.44	21.28	26.67	25.18	21.03	16.81	28.87	18.90	
	25.96	15.88	31.32	24.94	25.73	24.62	29.40	13.30	

Table 10. Mean Time Spent in Obtaining Medical Services for Scheduled (Well-baby and Routine Physical) Patients

		Present Summer Input Level		Present Winter Input Level		25% Increase to Summer Input		25% Increase to Winter Input	
		M	W	M	W	M	W	M	W
Current Policies	2 Doctors	33.74	25.64	28.37	25.95	29.66	31.99	28.48	31.76
		33.17	23.37	24.58	24.94	27.19	31.47	32.83	31.49
		24.85	24.70	23.67	24.46	27.56	15.37	31.35	32.03
	3 Doctors	22.10	18.08	16.30	18.65	21.94	25.15	19.12	23.26
		22.93	19.69	17.10	18.62	24.25	15.59	21.50	22.63
		23.98	18.57	15.77	18.24	21.54	23.31	21.10	22.89
	4 Doctors	18.62	15.41	20.21	16.03	17.21	18.96	20.51	20.02
		20.22	16.07	28.34	15.40	16.52	19.17	20.99	19.87
		16.71	15.48	18.41	16.31	16.23	19.13	19.77	19.02
Suggested Policies	2 Doctors	13.61	17.75		17.46	18.85	15.19		17.20
		13.26	19.50	N/A	15.07	20.08	16.79	N/A	15.48
		12.87	17.08		14.64	28.36	15.77		19.66
	3 Doctors		14.85		10.38		15.98		15.36
		N/A	15.47	N/A	12.08	N/A	16.02	N/A	12.14
			15.48		11.51		15.76		14.24
	4 Doctors		13.59		11.36		14.24		12.46
		N/A	13.13	N/A	10.58	N/A	13.70	N/A	12.49
			14.29		10.88		14.82		11.78

Table 11. Average Doctor Utilization

	Present Summer Input Level		Present Winter Input Level		25% Increase to Summer Input		25% Increase to Winter Input		
	M	W	M	W	M	W	M	W	
	90.94	58.17	96.96	89.00	95.52	71.54	99.01	78.62	Current Policies
2 Doctors	73.93	53.48	96.79	66.21	94.75	69.98	97.21	80.59	
	76.40	55.42	96.75	65.92	96.54	81.27	94.63	81.22	
	51.40	27.87	75.21	44.78	63.10	53.45	82.02	58.45	
3 Doctors	47.02	32.57	75.14	38.08	66.90	79.47	87.56	51.95	
	54.65	37.10	63.13	46.57	68.80	52.65	76.68	55.64	
	29.67	23.85	61.70	40.42	44.76	40.56	60.58	43.14	
4 Doctors	38.06	24.82	43.58	36.47	48.40	39.31	59.83	37.69	
	36.01	23.32	56.67	34.86	52.77	36.10	69.64	46.85	
	55.60	76.39	89.79	77.62	89.99	78.11	95.87	91.26	Suggested Policies
2 Doctors	62.30	81.08	94.81	78.12	90.71	79.53	95.61	91.38	
	71.50	77.24	88.22	87.32	93.96	82.63	95.12	88.24	
	34.52	63.42	77.91	50.34	55.30	70.26	77.10	67.23	
3 Doctors	46.12	64.97	60.54	59.11	67.33	71.35	68.95	64.29	
	39.41	64.11	60.28	49.90	51.44	72.18	77.26	66.46	
	24.25	47.65	34.70	39.46	40.11	58.04	60.87	51.57	
4 Doctors	36.15	46.52	39.66	40.77	35.44	54.63	55.12	48.63	
	33.36	46.42	48.53	46.49	38.15	59.68	59.27	40.59	

Table 12. Termination Time for Clinic Operation

		Present Summer Input Level		Present Winter Input Level		25% Increase to Summer Input		25% Increase to Winter Input	
		M	W	M	W	M	W	M	W
Current Policies		---	---	4:16	4:10	4:14	---	5:12	5:17
	2 Doctors	---	---	4:38	---	---	---	5:17	4:38
		---	---	---	4:15	4:49	---	4:11	5:46
		---	---	---	---	---	---	---	---
	3 Doctors	---	---	---	---	---	---	---	---
		---	---	---	---	---	---	---	---
		---	---	---	---	---	---	---	---
	4 Doctors	---	---	---	---	---	---	---	---
		4:07	---	---	---	---	---	---	---
Suggested Policies		4:02	---	---	---	4:03	---	5:32	4:38
	2 Doctors	---	---	---	---	---	---	5:16	4:15
		---	---	4:23	---	4:25	--	4:41	4:33
		---	---	4:19	---	---	---	---	---
	3 Doctors	---	---	---	---	---	---	---	---
		---	---	---	---	---	---	---	---
		---	---	---	---	4:03	---	---	---
	4 Doctors	---	---	---	---	---	---	---	---
		---	---	---	---	---	---	---	---

NOTE: Unless otherwise indicated, clinic operation was terminated at 4:00.

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